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CORRELATION OF THE CENOZOIC THROUGH ITS MAMMALIAN LIFE

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XIII[1]

The sea borders of the United States may be correlated with each other and with those of Eurasia in Cenozoic times through their invertebrate life, but for the vast interior of the American continent we must depend chiefly upon the mammals and in a less degree upon the reptiles, fishes, insects, and plants. I foresee great aid through these latter sources, but it is clear that the mammals will always afford the chief means of correlation, since in all parts of Europe mammal-bearing formations alternate with marine shell-bearing formations.

The standard divisions of Cenozoic geologic time will always be those established in Europe. The problem set before the paleontologists of our country is therefore to compare and establish our time divisions as closely as possible with the European standards. For this reason since 1899 I have been pursuing an exact investigation of the sequence of mammalian life in America and in the European Tertiary formations, and have enlisted the co-operation of many European and American paleontologists in the hope that such precise

[1] This article, which should have appeared as No. XIII in the series of correlation papers published last year, did not reach the *Journal of Geology* in time to be published in its proper place, in No. 7, 1909.

data may be obtained as to secure common understanding and usage of chronologic terms in the two countries.

Previous to 1898 scattered attempts at the correlation of European horizons *inter se* were made by Dawkins, Schlosser, Osborn, Depéret, and others, but it was not until June, 1905, that there began in the *Comptes rendus* a remarkable series of papers by Depéret entitled "L'évolution des mammifères tertiaires," covering with fulness the whole subject of the succession of mammalian life in Europe, the correlation of all the known horizons, with theories as to the migrations between the continents of Eurasia, North America, and Africa. I am not in accord with Depéret on many of these theories but I accept in full his correlation of the mammal-bearing horizons on the continent, together with his subdivisions of geologic time.

Similarly in America there are the pioneer correlations of Leidy of the American formations with each other and with those of Europe, followed with increasing precision by those of Cope, Marsh, Scott, Clarke, Dall, and Osborn. In 1899 Matthew published *A Provisional Classification of the Freshwater Tertiary of the West*, and this together with his *Faunal Lists of the Tertiary Mammalia of the West*, published in 1909, afforded the American bases for Osborn's *Cenozoic Mammal Horizons of Western North America*, published in 1909, in which for the first time the succession of the mammalian life of the New and Old Worlds is closely compared.

In the meantime increasingly accurate field methods, especially in the horizontal recording of levels after methods introduced by Osborn, Hatcher, and Wortman, have resulted in the subdivision of the old "formations" of Leidy, Cope, and Marsh into successive *Life-zones* similar to those long in use in invertebrate paleontology. These life-zones are obviously as important in questions of time as they are in questions of phylogeny or descent; they narrow down the old correlation standard of the comparison of similar specific and generic stages to different levels; they add greatly to the possibilities of precise comparison in respect to the newer data of correlation, such as detailed evolution of related forms, the simultaneous introduction of new forms by migration, the predominance or abundance of certain forms, the convergence and divergence of American and European faunas.

Putting together all these facts of various kinds, the first result is the proof that the mammalian life of Eurasia and America in Tertiary times passed through a series of grand phases of union, of divergence, of reunion, and perhaps again of divergence. There are seven of these phases.

In the *first*, in Basal Eocene times, we find North America, Europe, and possibly South America peopled with archaic mammals of Mesozoic ancestry.

In the *second* faunal phase, of Lower Eocene times, we observe the first modernization, which occurs simultaneously in Europe and North America, by the invasion of many modern families of mammals, which intermingled with the archaic; the life of Europe and North America continues to be very similar.

In the *third* faunal phase, beginning in Middle Eocene times, the mammals of America and Europe gradually diverge and undergo an independent evolution with little or no faunal interchange; at the close of the Eocene the two faunas are very far apart.

In the *fourth* faunal phase, beginning in Lower Oligocene times, there is a sudden reunion of New and Old World life. At the same time there occurs in both countries a second very surprising modernization apparently by the further invasion of modern forms from the north.

A *fifth* faunal phase occurs in the Middle Miocene, when there is a fresh reunion in the New and Old Worlds by the arrival in America of the proboscideans and the short-limbed rhinoceroses.

Then follows a long period of independent evolution in the two countries until in the Middle Pliocene we enter a *sixth* faunal phase, in which a close land connection with South America is re-established, after an interval of separation reaching back into Eocene times.

Finally a *seventh* faunal phase occurs in Pleistocene or Glacial times, when all the larger North American mammals become extinct, as well as the south American invading stocks, while North America is replenished by a large fauna from Eurasia.

It will be noticed that these phases are in no way coincident either with the greater or with the lesser time divisions, for the obvious reason that these time divisions have all been established on the basis of the evolution of invertebrate life in Europe.

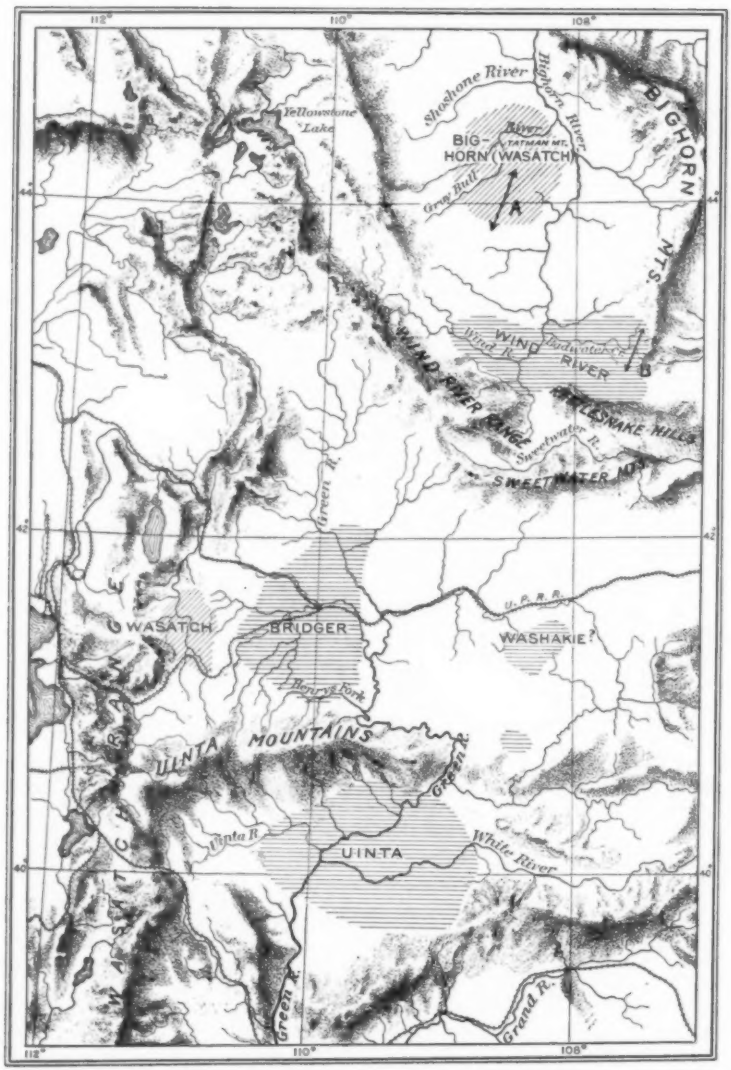

FIG. 1.—Map of southwestern Wyoming and northern Utah, showing partial areas of the Wasatch, Wind River, Bridger, and Uinta formations. Extensive areas of the Wasatch are purposely omitted. A, B, lines of sections by F. B. Loomis.

EOCENE

Basal.—The very opening of the Eocene furnishes one of the most brilliant examples of the possibilities of precise correlation through vertebrate life. Changes occurring in the interior of the American continent may be compared precisely with those along the northern coasts of France and Belgium. In each case great forms of reptilian life persist to the very close of the Cretaceous; the conditions of the American "Laramie," "Hell Creek," or Ceratops beds are similar to those of the Danian or Maestrichtian of Belgium; both mark the abrupt termination of the Age of Reptiles; both are overlaid by beds containing a number of very distinctive types of archaic mammals mingled with those of distinctive reptiles (*Champsosaurus*) found alike in the Puerco of Mexico, the Fort Union of Montana, the Thanetian of northern France. Thus we believe the opening of the Tertiary admits of close correlation in the Old and New Worlds. The succeeding rich Puerco-Torrejon mammalian life of New Mexico, so far as known, parallels that of the Thanetian (including the Cernaysian) stage of northwestern Europe. It is all *Paleocene*, or Basal Eocene.

Lower.—The beginning of the Lower Eocene is clearly defined in the Rocky Mountain region and with equal sharpness in northern France and Belgium by the appearance of *Coryphodon*, and by the opening of the second faunal phase with its advent of modernized life. Our Lower and Upper Wasatch correspond respectively with the Sparnacian and Ypresian stages of France. It is represented in deep and fairly rich exposures in northern New Mexico and in western, central, and northern Wyoming.

The Wind River of central Wyoming together with the Lower Huerfano near the Spanish Peaks of Colorado marks the upper life-zone of *Coryphodon* and may prove to correspond closely with the Ypresian of France. In the Rocky Mountains the Wind River is readily distinguished by the survival of a number of characteristic Lower Eocene types (*Coryphodon*, *Phenacodus*) and the fresh arrival of a number of equally characteristic Middle Eocene types (uintatheres, titanotheres). It is consequently an ideal transition fauna. Unfortunately the formations believed to be of corresponding age in France are poor in mammal remains.

From this time on to the summit of the Eocene we are passing into the third faunal phase, or divergence and independent evolution of the life of Europe and America. Consequently close correlation is

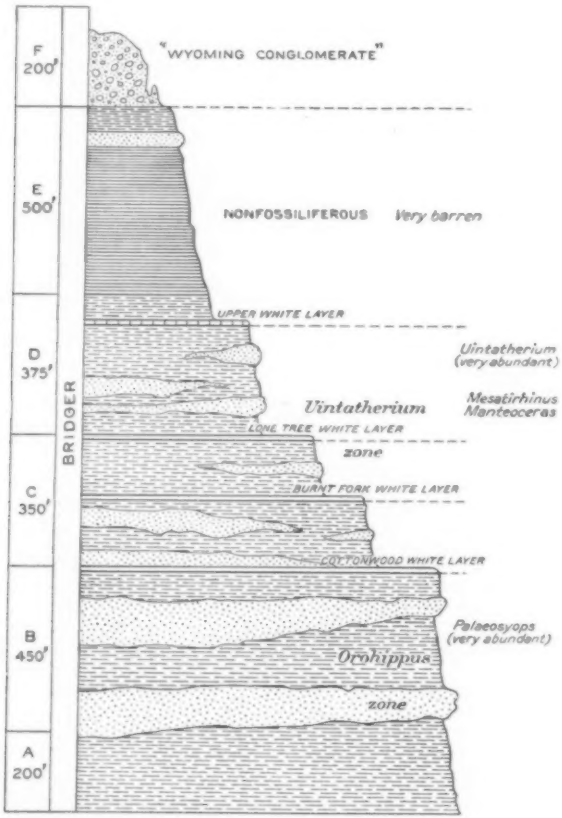

FIG. 2.—Columnar section of the Bridger formation, Henrys Fork, western Wyoming. After studies by Matthew and Granger, 1902.

almost impossible; at no period in the Tertiary were the Nearctic and Palearctic faunas so widely separated.

Middle.—With the American Bridger, 1,800 feet in thickness, we enter the Middle Eocene and broadly compare the Lower Bridger

with the Lutetian and the Upper Bridger with the Bartonian of France. The precise survey of the life-zones of the Bridger by Granger and Matthew marks one of the greatest advances of recent times.

Similarly under the direction of the present writer the Washakie

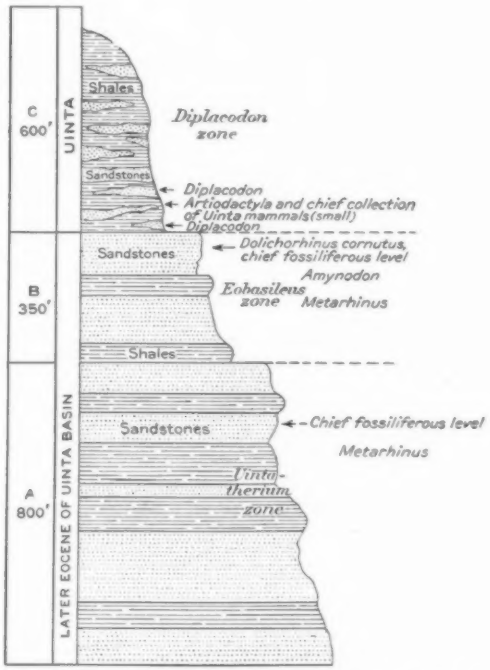

FIG. 3.—Columnar section of the Uinta formation, northern Utah. In A and B the diagram does not properly represent the irregular nature of the so-called sandstones and clays, which are probably in part coarser and finer volcanic-dust deposits. Modified from notes by O. A. Peterson, 1894. Faunistic studies of Osborn.

of central Wyoming has been surveyed precisely by Granger, proving that the Lower Washakie is identical in age and in its mammalian life with the Upper Bridger and broadly corresponds with the Bartonian, or closing stage of the Middle Eocene of France. We are now in the Uintatherium Zone, all the famous discoveries of Cope and

Marsh having been made at this level. Here belongs also the beginning of the Uinta deposition of northern Utah.

We now pass into the Eobasileus Zone of the Upper Washakie and the Middle Uinta, in which the long-headed uintatheres described by Cope as *Eobasileus* and *Loxolophodon* occur mingled with remains of highly specialized Eocene titanotheres. This is apparently the lower level of the Upper Eocene and is broadly comparable with the Ludian stage of France.

Upper.—The succeeding Ligurian stage of France may be paralleled with the upper, or true Uinta, the Diplacodon Zone of Marsh. The zonal type is a large titanothere with well-developed bony horns, transitional in many characters to the Lower Oligocene titanotheres; in fact, the summit of the thick Diplacodon Zone of 600 feet will probably prove to coincide with the base of the White River Group on the great plains. Quite recently, during the summer of 1909, the much-desired sequence of Oligocence and Eocene strata was discovered by Mr. Granger of the American Museum expedition. The Diplacodon Zone has been discovered in the Wind River region of Wyoming underlying the Titanotherium Zone.

The Ligurian stage of France is that of the famous Gypse de Montmartre discovered by Cuvier, full of paleotheres and anoplotheres, a mammal fauna totally distinct from that of the Rocky Mountain region.

OLIGOCENE

Lower.—The Oligocene opens in the New and Old Worlds with the fourth faunal phase and second modernization, which since it affects alike Europe and America probably indicates a fresh migration from the great unknown northern, or Holarctic region. With this migration close faunal resemblance is re-established with western Europe, and thereby comes a welcome means of geologic correlation; in other words, we may with considerable confidence consider that the base of the White River group was nearly coincident with the inferior Tongrian of France. Sixteen new families of mammals appear in America, all of them still existing, and seventeen modern, or still existing, families appear in Europe. This momentous faunal change in North America is partly attributable to the fact that this is our first glimpse of the life of the Great Plains.

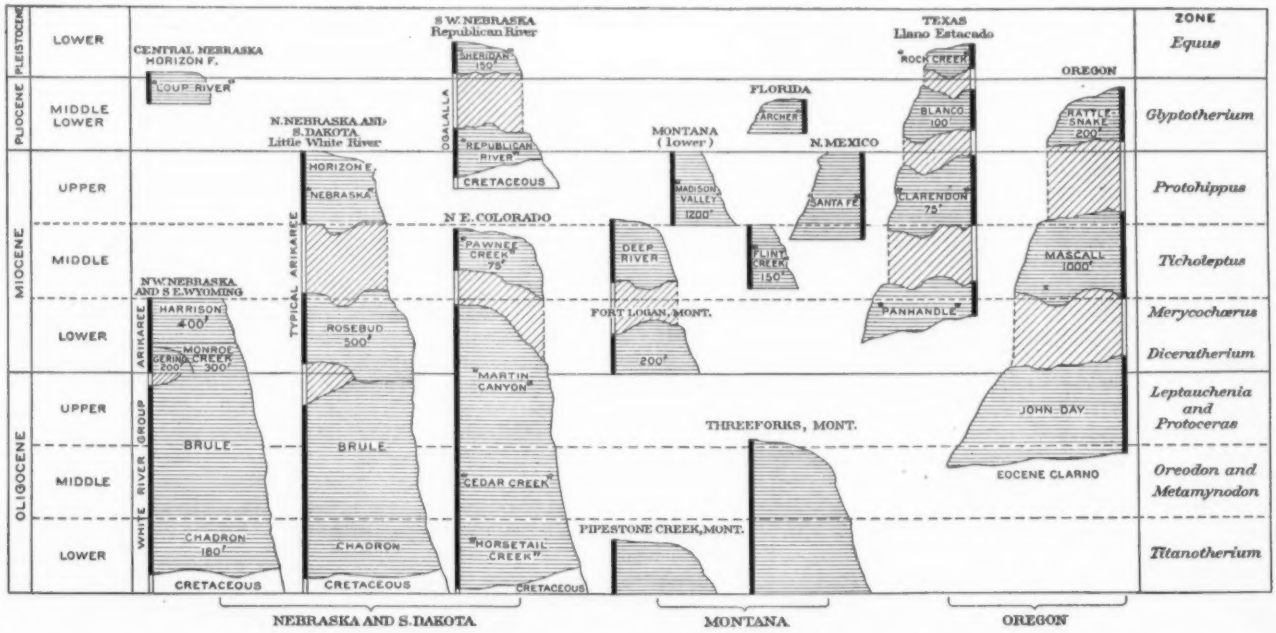

FIG. 4.—Provisional correlation of some of the chief epicontinental Oligocene-Pleistocene deposits and formations of the West in which fossil mammals have been recorded. Unlike the sections in the other figures, these sections are not represented to scale; they are purely conventional. After W. D. Matthew and H. F. Osborn, 1907.

Middle.—The Lower Oligocene, or Titanotherium Zone, most accurately surveyed by Hatcher, is succeeded by the Middle Oligocene or Oreodon Zone, broadly comparable with the Superior Tongrian and Stampian of France, both containing similar types of amphibious rhinoceroses and many other mammals. One of the chief points of interest here is the sharp separation discovered by Matthew between the plains-living mammals buried in the so-called clays, or finer deposits, and the forest-living mammals buried in the coarser intrusive river sandstones.

Upper.—The close of the Oligocene takes us into the John Day tuff deposits of Oregon, and is generally parallel with the Aquitanian Stage of France, typified by St. Gérand-le-Puy. It is the Diceratherium Zone, or the climax of the evolution of the pair-horned rhinoceroses in both countries. We pass also into the Upper Merycochoerus Zone at the summit of the John Day and at the base of the Arikaree formation extending along Pine Ridge of South Dakota. Here we are again in difficulty in determining just when the American Oligocene should be regarded as closing and the Miocene as beginning. An abundance of diceratheres and entelodonts still betokens Oligocene times, but it is possible that we may be in the Miocene. This is one of the doubtful points requiring further investigation.

MIOCENE

The solution of the Lower and Middle Miocene sequence in America through the discoveries of Hatcher, Peterson, and of Matthew marks another great advance of recent years.

Lower.—There is no question that in the Upper Arikaree, the Upper Harrison of Hatcher, and the Upper Rosebud of Matthew we are fairly in Lower Miocene times corresponding with the Burdigalian of Europe. There is now considerable faunal difference between the New and Old Worlds. The Proboscidea certainly enter Europe at this time, and one of the debated points is when they first appear in North America.

Middle.—The Vindobonian, or Middle Miocene of Europe, divided into the three successive stages of Sansan, Simorre, and St. Gaudens, is again with considerable confidence compared with the Deep River of Montana, and the Pawnee Buttes of Colorado, through

the researches of Scott and Matthew. Here we enter the fifth faunal phase, marked by fresh migrations and the first undoubted appearance of the proboscideans and short-limbed rhinoceroses in America, both arrivals from the Old World. Physiographic changes are indicated in evidence of increasing summer droughts, numerical increase of animals adapted to plains-living and the semi-arid conditions, in the disappearance of most of the browsing types. The correlation is, however, by no means close at present, because the life of Europe and the great American plains is of different local habitat.

Upper.—In the Upper Miocene, however, we are again somewhat more confident in correlating our Hipparion and Procamelus Zone, the "Loup Fork" of early writers, with the Pontian or Pikermi stage of Europe typified by the wonderful advent of the plains fauna of Asia which spreads all over southern Europe, probably into Africa and the far East of southern Asia and China.

PLIOCENE

It is difficult again to demarkate the close of our Miocene and the beginning of our Pliocene. For the first time in American Tertiary history an invertebrate paleontologist (Dall) comes to our aid through discovering that the mammals of the Alachua Clays of Florida overlie certain true Lower Pliocene molluscs. The mammals of these clays are comparable to those of the Republican River of Kansas, and we are consequently disposed to place the latter in the Lower Pliocene. It is at least a more recent phase than the "Loup Fork," and is hence distinguished as the Peraceras Zone, from the presence of a number of broad-skulled hornless rhinoceroses.

Lower.—Of undoubted Lower Pliocene age is the recently discovered Snake River deposit of western Nebraska, the Neotragocerus Zone, and the Virgin Valley and Thousand Creek of Nevada. The arrival at this time of true Old World tragocerine and hippotragine antelopes from Asia, as identified by Matthew and Merriam, is one of the most noteworthy discoveries in recent paleontology. These antelopes may prove to demarkate our Lower Pliocene, in which case the Republican River will be pushed back into the close of th Miocene because it certainly does not contain these Old World forms.

The Lower Pliocene, or Plaisancian, of Europe is represented by

PRELIMINARY CORRELATION

		EUROPE	ASIA	NORTH AMERICA
PLIOCENE	Upper	SICILIAN	Siwaliks	"Loup River"
	Middle	ASTIAN	Siwaliks	Blanco
	Lower	PLAISANCIAN	Siwaliks	Thousand Creek Rattlesnake and Republican River
MIOCENE	Upper	PONTIAN	Manchhar	"Loup Fork" Madison Valley Clarendon
	Middle	VINDOBONIAN	Manchhar	Deep River Pawnee Buttes Mascall
	Lower	BURDIGALIAN		Arikaree "Upper Harrison" Rosebud
			AFRICA	
OLIGOCENE	Upper	AQUITANIAN		Harrison (Lower) John Day White River(Upper)
	Middle	STAMPIAN		White River (Middle) Brulé Clays
	Lower	SANNOISIAN	Fayûm	White River (Base) Cypress Hills Pipestone Creek Chadron
EOCENE	Upper	LUDIAN	Fayûm	Uinta (Upper and Middle) Washakie (Upper)
	Middle	BARTONIAN		Uinta (Lower) Washakie (Lower) Bridger (Upper)
		LUTETIAN		Bridger (Lower) Huerfano (Upper)
		UPPER YPRESIAN		Bridger (Lower) Huerfano (Upper) Green River
	Lower	LOWER YPRESIAN		Huerfano (Lower) Wind River Wasatch (Upper)
		SPARNACIAN (Upper Landenian of Belgium)		Wasatch (Lower)
		UPPER THANETIAN (=Cernaysian) (Lower Landenian of Belgium)		Torrejon Fort Union
	Basal	LOWER THANETIAN		Puerco Fort Union
CRETACEOUS	Uppermost	DANIAN=Maestrichtian (Terrestrial) (Marine)		Hell Creek

the mammalian life of Casino, which is very sharply demarkated from that of Pikermi.

Middle.—The Astian, or Middle Pliocene, life of France, typified at Roussillon and Montpellier, is broadly comparable with the Blanco of Texas, where we enter the sixth faunal phase, marked by the invasion of South American armored edentates, or glyptodonts, into the southern United States. These deposits are accordingly known as the Glyptotherium Zone. They mark a great advance upon those of the Republican River.

Upper.—The Upper Pliocene, or Sicilian, stage of Europe, typified by the Val d'Arno fauna of northern Italy, is hardly comparable with any American horizon. We are here on the border-line between Pliocene and Pleistocene, and a great deal of research is still needed. The Peace Creek deposits of Florida (Dall) may help us because here we discover an Equus and an Elephas Zone overlaid by marine Upper Pliocene molluscs. Rather primitive forms of Equus and Elephas are also characteristic new arrivals of the Upper Pliocene, or Sicilian, stage of Europe. The same doubt applies to the little-known "Loup River" of Nebraska, in which *Equus* and *Elephas* were discovered by Leidy many years ago.

PLEISTOCENE

Perhaps the most striking determinations which await the mammalian palaeontologist are those which close comparison of the Pleistocene stages in the New and Old Worlds will afford. In Europe we have four great series of correlation data, namely:

The geologic succession of the glacial depositions;

The faunal succession especially among the higher mammals;

The evolution of stone implements of human manufacture;

Stages in the skeletal evolution of man.

In America the two kinds of data connected with the evolution of man are entirely wanting, and we are thrown back on the geologic and the faunistic divisions; consequently close comparison in these two lines of evidence common to both countries is all the more necessary. In Europe it is possible to distinguish four grand faunistic phases, namely:

The first early Pleistocene fauna, Eolithic Stage of culture;

Second or mid-Pleistocene fauna, Eolithic and early Paleolithic Stages;

Third or Upper Pleistocene fauna, late Paleolithic Stage;

Fourth, post-Glacial fauna, Neolithic Stage.

From close study of the Pleistocene life of North America there is promise of correlation with Europe through identification of American with European glacial and interglacial periods, through the discovery and identification of interglacial faunas, as in the Aftonian and Toronto deposits, through the careful recording of the time of extinction of native types and of the time of arrival of new types to demarkate our Pleistocene also into great successive life-zones.

The chief progress made thus far (1909) is that we begin to recognize the following divisions of American life:

Early and mid-Pleistocene life of the plains, *Equus* Zone;

Mid-Pleistocene life of the forested regions, *Megalonyx* Zone;

Life of the maximum cold period, *Ovibos* Zone;

Life of post-Glacial times, Zones of *Cervus* and *Homo*.

Especially interesting is the coincidence of the maximum cold period, or *Ovibos*, Musk Sheep Zone of America, with the maximum cold period, or *Elephas primigenius*, *Rangifer tarandus* Zone of Europe.

It is obvious that we should never expect to discover as clear demarkation of the life-zones in America as in Europe because of the vast refuge areas of the mammals in the south. In Europe the glacial advances are sharply punctuated by the appearance and disappearance of species. In America apparently such appearances and disappearances are gradual.

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THE GEOLOGIC RECORD OF CALIFORNIA

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The geologic record of California is exceedingly complete for a single geographic region, because of the two ancient and persistent seas that covered some portion of its surface during each geologic period. These seas were the Pacific Ocean and the Great Basin Sea.

The geologic history of California is given below chiefly in the form of tables, for the sake of brevity, and without a discussion of the faunas and floras of the various formations, since that would extend the paper beyond the size intended. Such a discussion is reserved for a later paper.

The tables here given have been based on a critical study of all the papers on the stratigraphy of California, and on the writer's experience in this field for a period of seventeen years, of which a large part has been spent in field study.

Great Basin Sea.—The older portion of the geologic record, from the Cambrian to the top of the Middle Jurassic, has been preserved chiefly in the sediments of the Great Basin Sea, while during those ages that part of California which was afterward covered by the Pacific Ocean was either above water, or has had its sediments so much metamorphosed that their age is not positively determinable.

The Great Basin Sea of Paleozoic and early Mesozoic time covered approximately the area of the Great Basin of the present age, sometimes more, and sometimes less, dwindling away gradually from the noble expanse of the Carboniferous Sea to the shrunken remnant in early Mesozoic time. This basin at all times was directly connected with the Pacific Ocean, by a broad passage to the northwest; and during a part of the Paleozoic, especially during the period of the Coal Measures, it was joined to the Mississippian Sea. At all other times it was exclusively western, and the marine Triassic and Jurassic history of the United States is its peculiar property. It has played

ARCHAEAN	PALEOZOIC															
	CAMBRIAN			SILURIAN		DEVONIAN		CARBONIFEROUS								
	Lower			Upper		Middle		Mississippian		Coal Measures						
				Niagara												
	Silver Peak			Grizzly		Sacramento		Bragdon	McCloud							
				Mont-gomery		Kennett			Baird	McCloud Limestone	Nosoni					
Schists and gneisses of the Sierra Nevada	Limestones of White Mountains with Olenellus, and banks of Archaeocyathus			Limestone of Plumas County, with Niagara fauna		Limestones of Kennett, with coral reefs, Favosites canadensis		Bragdon shales of Trinity County	Black siliceous shales of McCloud River, with Productus giganteus, P. burlingtonensis, Orthis michelini	Gray limestones of McCloud River with Fusulina robusta, F. cylindrica, Clisiophyllum gabbi	Sandstones and tuffs of Shasta and Plumas counties with Fusulina elongata					

GEOLOGIC COLUMN OF CALIFORNIA

Standard Marine Section

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GEOLOGIC COLUMN OF CALIFORNIA

| STANDARD MARINE SECTION | | |

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CENOZOIC

System	Series	Formation
Quaternary	Pleistocene	Terrace formations
		Glacial beds
		Santa Clara lake beds
		Tulare lake beds
		Upper flora of Mt. Diablo region
Tertiary	Pliocene	Paso Robles
		Merced: Sandstones of Lake Merced with Cardium meekanum and Scutella interlineata
		San Diego: Purisima
		San Diego: Sandstones of San Diego and Half Moon Bay, with Pecten healeyi
	Miocene, Upper	San Pablo: Sandstones of San Pablo Bay and the Coalinga region, with Pecten pabloensis and Pecten oweni
	Miocene, Middle	Santa Margarita: Sandstones of Salinas Valley, with Pecten estrellanus, Ostrea titan, and Tamiosoma gregaria
	Miocene, Middle	Monterey: Monterey Shales with Pecten discus and Pecten peckhami
	Miocene, Lower	Vaqueros: Sandstones of Monterey and San Luis Obispo counties, with Turritella inezana and Mytilus mathewsoni
		Auriferous Gravels

very much the same part in the geologic history of North America as the ancient Mediterranean or Tethys did in the history of Europe, though on a much smaller scale, since it was epicontinental, and not intercontinental. The Cambrian, Silurian, and Devonian sediments of California are mere fragments of little area and thickness, representing only a small part of the entire time of those ages. The Carboniferous, however, is fairly complete, all three major divisions being fully represented by marine faunas. The Triassic period is well represented; the Lower Triassic is nearly as good as the standard American section of Idaho; the Middle Triassic has both of the greater divisions, although the main portion is not nearly so complete as the standard section of the West Humboldt Range in Nevada. The Upper Triassic of California is the standard for this epoch in America, and compares very favorably with the rest of the world in the richness of its faunas, and the completeness of the record. The Jurassic section of the Great Basin Sea is the most complete in the United States, having portions of each stage from Lias to Kelloway, inclusive; but it is fragmentary, the faunas being poorly preserved and scanty. It is not comparable with the Jurassic record of Alaska and British Columbia, and nowhere approaching that of South America. With this epoch the marine column of the Great Basin ends abruptly, as the sea was obliterated at the beginning of the Cordilleran revolution.

Pacific record.—The marine record of California from the bottom of the Upper Jurassic through the Quaternary was kept exclusively by the Pacific Ocean. This was divided between two provinces, or areas of sedimentation, the Sierra Nevada, and the Coast Ranges, but the distribution was not balanced. The Pacific province is one of the great geosynclines, with sediments approximating seventy thousand feet in thickness, and undergoing subsidence more or less continuously, though spasmodically, from the Triassic onward, interrupted by great periods of orogenic activity. This is a part of that grand structural feature of the continent of which the Great Valley, the Gulf of California, the Willamette Valley, and Puget Sound are mere remnants.

The recognizable Paleozoic and early Mesozoic sediments are confined to the Sierra Nevada, while the Cretaceous and Tertiary

GEOLOGIC RECORD OF THE GREAT BASIN SEA IN CALIFORNIA

CENOZOIC	Quaternary			Lahontan lake beds
	Tertiary			Miocene, Truckee, lake beds
				Eocene, Esmeralda, lake beds
MESOZOIC	Jurassic			Cordilleran revolution, uplift and metamorphism of Sierra Nevada and obliteration of the Great Basin Sea
			Middle	Hinchman tuff and sandstone of Plumas County, with Kelloway fauna, and reef-building corals
				Mormon sandstone and Thompson limestone of Plumas County with lower Oölite fauna
			Lower	Hardgrave sandstone of Plumas County, with Upper Liassic fauna
				Arietites limestones of Inyo County, California, and West Humboldt Range, Nevada
	Triassic		Upper	Pseudomonotis shales of Shasta and Plumas counties
				Hosselkus limestone of Shasta County, with coral reefs. *Tropites subbullatus* fauna.
			Middle	Pitt shales of Shasta. Star Peak limestone of West Humboldt Range, Nevada
				Black limestone of Inyo Range, with Middle Triassic fauna
			Lower	Gray limestone of Inyo Range, with Meekoceras fauna
PALEOZOIC	Carboniferous		Upper	Wildwood limestone of Trinity County, with Permian fauna
				Nosoni tuffs and shales of Shasta County, with fauna transitional to Permian
			Middle	McCloud limestone of Shasta County, with Coal Measures fauna, and coral reefs
			Lower	Baird shales of Shasta, with Asiatic Subcarboniferous fauna
				Bragdon shales of Trinity County, without definite fauna
	Devonian		Middle	Kennett limestones of Shasta County, with coral reefs, *Favosites*, *Diphyphyllum*, etc.
	Silurian		Niagara	Montgomery limestone of Plumas County, with reef-building corals
	Cambrian		Lower	Olenellus limestone of Inyo County, with reefs of Archaeocyathus
ARCHÆAN				Pre-Cambrian schists of Inyo County

strata are most complete in the Coast Ranges. The Sierran record is fragmentary, the formations being incomplete, separated by great unconformities, including great masses of tuffs and igneous rocks, and showing evidence of important recurring orogenic and volcanic activity.

The Coast Range province, too, showed this same phenomenon in its Paleozoic and early Mesozoic sediments, but from the bottom of the Cretaceous to the middle of the Miocene conditions were more uniform, indicating moderately quiet advance and retreat of the sea, with minor unconformities, smaller masses of igneous intrusives, and outpourings of surface lavas. The Coast Range revolution, about the middle of the Miocene epoch, broke the monotony of this history, and for a time there was much mountain-making activity. Minor outpourings of lava occurred along the coast, while farther to the northeast the Columbian lava flood overwhelmed an area of about two hundred thousand square miles, and the rejuvenation of the Sierra Nevada was beginning.

The Cretaceous section of the Coast Ranges is more complete than that of any other single province in America. It lacks only the uppermost portion, and shows a variety of conditions not seen anywhere else, from the boreal faunas of the Knoxville to the tropical faunas of the Horsetown and Chico epochs, with fossil floras interbedded in every formation.

The Tertiary marine section of the Coast Ranges is not only the most complete in America, but also more complete than that of any other single geographic region in the world. Every minor division is fully represented by marine faunas, and most of them have freshwater beds intercalated, with fossil plants and freshwater animals.

The Quaternary marine section of the Coast Ranges is the most complete that has been described, for this is almost the only known region where there has been much post-Quaternary orogenic activity. In nearly all other regions the Quaternary sediments are still buried under the oceans in which they were deposited.

ROCK-FORMING AGENCIES OF CALIFORNIA

Igneous rocks.—A large part of the surface of the state, a little less than one-half, is made up of igneous rocks. Of these the most

important group consists of deep-seated granitic rocks, granites, grano-diorites, diorites, and gabbros, compounds of feldspars and ferro-magnesian minerals, such as hornblendes, pyroxenes, and mica. The greatest of these batholites is the great igneous mass of the Sierra Nevada, making up the bulk of that mountain chain. Smaller batholites of similar character are in the Sierra Madre Range, the White Mountain Range, the Klamath Mountains, and in the Santa Lucia Mountains.

Associated with the deep-seated granitic rocks in nearly all these regions there are numerous dyke-rocks, similar in chemical nature to the parent masses, but showing only a small surface area.

A second group is composed of basic intrusives, chiefly peridotites, now largely changed to serpentine, rich in olivine and other ferro-magnesian minerals. These cover great stretches in the Coast Ranges, where they are largely of Franciscan age, older than the Cretaceous; they also form less extensive masses in the Sierra Nevada.

A third group is composed of lavas, mostly andesites and basalts, surface flows from volcanoes. These are chiefly of Tertiary age, Middle Miocene, and, together with the less important rhyolite flows, they cover broad areas in northeastern California, and smaller patches in all the other mountain regions of the state. The flows in northeastern California are a part of the Columbian field, and doubtless came from fissure-eruptions. The others came from ordinary volcanoes, though in most cases the volcanic cones are long since destroyed. Mt. Shasta and Lassen Peak are the two grandest volcanoes of the state, the southern extension of the Cascade Range, still preserving their ancient form and some feeble remnants of their old-time activity.

Inorganic sediments.—The greater part of the surface of California, a little more than half, is made up of sediments. These are of two groups, (1) inorganic, and (2) organic.

The inorganic sediments are far greater in thickness and areal extent, sandstones and shales, derived from the decay of crystalline rocks. The quartz and undecomposed feldspars furnished the sand grains, and the decomposed feldspars furnished the clay for the shales. The sandstones of California are remarkable for the large quantity they contain of undecomposed fragments of minerals derived

		MEDITERRANEAN REGION	ORIENTAL REGION	BOREAL REGION	WEST AMERICAN REGION
RECENT			Marine fauna of Japan		Marine fauna of California
QUATERNARY					
					Warm water marine fauna of Calif.
			Cold water marine fauna of Japan		Cold water marine fauna of Calif.
TERTIARY	Neocene	Cold water marine fauna	Cold water marine fauna of Japan		Cold water marine fauna of Calif.
	Eocene	*Venericardia planicosta* Zone			*Venericardia planicosta* Zone
CRETACEOUS	Upper	*Schloenbachia* fauna of Europe	*Schloenbachia* fauna of Japan, South India, and East Africa	Queen Charlotte Islands	*Schloenbachia* fauna of California
	Lower			*Aucella* fauna of North Europe, North Asia, and Alaska	*Aucella* fauna of the Knoxville Strata in California
JURA	Upper			*Cardioceras* fauna with *Aucella* in Russia	*Cardioceras* fauna with *Aucella* in California
	Mid.		Mediterranean type in India	*Cadoceras* fauna of Alaska and the Boreal region	Mediterranean type in California
	Lower	*Arietites* fauna	*Arietites* fauna in the Indian Ocean	*Arietites* fauna of Alaska	*Arietites* fauna in California and Nevada
TRIAS	Upper		*Pseudomonotis ochotica* fauna in Japan	*Pseudomonotis ochotica* fauna in Alaska and North Siberia	*Pseudomonotis ochotica* fauna in California and Nevada
		Tropites subbullatus fauna	*Tropites subbullatus* fauna in India	*Dawsonites* fauna of the Arctic Ocean	*Tropites subbullatus* fauna in Calif.
	Middle	*Ceratites trinodosus* fauna	*Ceratites trinodosus* fauna	*Ceratites* fauna of Spitzbergen	*Ceratites trinodosus* fauna, Nevada
		Beyrichites fauna, Gulf of Ismid			*Parapopanoceras* fauna in Calif.
	Lower	*Columbites* fauna, Albania	*Hedenstroemia* fauna of India	*Olenkites* fauna of North Siberia	*Columbites* fauna in Idaho
		Tirolites cassianus fauna			*Tirolites* fauna in Idaho
			Meekoceras fauna of India	*Meekoceras* fauna of Spitzbergen	*Meekoceras* fauna in California and Idaho
CARBONIFEROUS		Atlantic type	Asiatic type in India, Japan, and China	Asiatic type in Alaska and Siberia	Asiatic type in California

GEOGRAPHIC RELATIONS OF WESTERN AMERICAN FOSSIL FAUNAS

ARCHAEAN ?	PALEOZOIC	MESOZOIC			
	Paleozoic	Triassic	Jurassic		Cretac
	Santa Lucia		Franciscan		Knoxville	Ho to
	Santa Lucia limestone gneisses and granites, without definite fossils	Wanting ?	Cherts, limestones, shales, and schists without definite fossils and with great intrusions of basic igneous rocks, all pre-Cretaceous, and in part possibly even Triassic in age	Cordilleran revolution	Knoxville shales and conglomerates	ties
						Shasta flora
				Oregon flora		nia and southern Oregon, associated with Knoxville and Horsetown marine species
				Plant beds of northern California and southern Oregon, supposed to be of Jurassic age		

Archaean ?	Silurian	Carboniferous	Triassic of the Gold Belt		Mariposa	Colfax	
	Grizzly	Calaveras formation		Oroville flora			
Older gneisses of Sierra Nevada	Montgomery limestone of Plumas County, with Niagara fauna	Limestones and quartzites of the Sierra Nevada, with Carboniferous fossils	Sailor Canyon shales Genesee Valley limestone and shales	Oroville flora, with cycads of Middle Jurassic age	Mariposa shales, with marine fossils of Upper Jurassic age	Colfax shales and altered tuffs, and igneous rocks. Marine record almost destroyed	Cordilleran revolution
							Erosion period. Record wanting

| Mesozoic | | |

			Coast Ranges		Sierra Nevada	
Cenozoic	Quaternary		Terrace			Terrace gravels
			San Pedro sandstones			
			Canyon-cutting epoch			Glacial beds
	Tertiary	Pliocene	Merced sandstones	Santa Clara lake beds		
			San Diego and Purisima sandstones	Tulare lake beds		
		Miocene	San Pablo and Etchegoin sandstones	Lake beds of Tesla, with Upper Miocene leaves	Auriferous Gravels	Post-volcanic gravels, with Upper Miocene leaves
			Santa Margarita sandstones			
			Coast Range revolution			Chief volcanic period
			Monterey shale			
			Temblor sandstone			Ocoya Creek sandstones, with marine fossils
			Vaqueros sandstones			

from the igneous rocks, so that they more often arkose and greywacke than true sandstones.

Thick beds of aluminous shales, now largely changed to slates, are found in the Carboniferous and Jurassic rocks of the Sierra Nevada, and to a less extent in the Franciscan formation of the Coast Ranges. The Auriferous Slates also form the surface rocks of considerable areas in the Klamath Mountains.

Less altered shales are extensively developed in all the later formations of the state, from the Lower Cretaceous upward, although not on such a grand scale as in the older periods.

The greatest individual mass of sediments in California is formed by the Quaternary and Pliocene fluviatile deposits of the Great Valley. This mass is about four hundred miles long by fifty in width, and is several thousand feet thick in the middle, thinning out toward the edges, surpassing the enormous mass of Tertiary sediments. These valley deposits have been bored to a depth of three thousand feet, without reaching bed-rock, but there are too few deep borings for an estimate of the average thickness to be possible.

A second great mass of clastic sediments is seen in the Tertiary sandstones of the Coast Ranges, which extend nearly the entire length of the state, and have a total thickness of about fifteen thousand feet, although not all of this at any one place. A remnant of this series is seen along the western flank of the Sierra Nevada in the marine and brackish-water Ione formation, and the upland equivalent is seen in the Auriferous Gravels.

A third great mass of sandstones is found in the Cretaceous of the Coast Ranges, where a thickness of about thirty thousand feet was deposited. This thickness surpasses by far that of the Tertiary sandstones, but the areal extent is much less. These, too, overlapped on the foot of the Sierra Nevada.

Smaller masses of sandstone, now largely changed to quartzite, are seen in the early Mesozoic and Paleozoic formations of the Sierra Nevada and Coast Ranges, but nowhere forming extensive surface areas.

On the western flank of the Sierra Nevada, throughout the Gold Belt, there are in the late Paleozoic and in the late Jurassic thick beds of tuffs, or volcanic ash, now altered to greenstone schists.

These in places have a thickness of several thousand feet, but do not form considerable areas of the surface rocks.

Organic sediments.—These do not make much of a figure on the areal map of the state, but play a large part in its economic history. They are limestones, siliceous shales, and plant accumulations in the form of coal or lignite.

The limestones are entirely of organic origin, with the exception of some smaller occurrences of late spring deposits, or calcareous tufa, which, however, are large enough to be used in the manufacture of cement.

The great masses of limestone are confined to the Paleozoic and early Mesozoic, though as late as the middle of the Jurassic period there are some large beds of limestone. They are formed of ground-up shells, corals, and foraminifers that lived in quiet, clear waters, but are now largely crystalline, most of the evidence of their organic origin having been destroyed in the great mountain-making revolutions that have passed over them. The formation of limestone on a large scale in California was confined to epochs that we know from other evidence were warm, and also to epochs when sheltered, clear seas covered portions of the state. In such seas corals and foraminifers abounded, and the evidence of their rock-forming activity is still visible in the coral reefs of the Paleozoic and Triassic, and the Fusulina limestone of the Carboniferous.

From the middle of the Mesozoic up to the Eocene it was still warm enough at times for reef-building corals, and foraminifers to have flourished in the seas of California; but the warm epoch of the Middle Jurassic was a time of igneous activity, and during the Cretaceous there was too much sand and mud poured into the water for these organisms to find a favorable habitat.

Limestones, at least in part formed by corals, have a thickness of several thousand feet in the Cambrian of Inyo County, but the areal extent is unknown. The Devonian of Shasta and Siskiyou counties shows coral reef rock to the thickness of several hundreds of feet, of small area. These are all surpassed in the great masses of Carboniferous limestone, of the White Mountains, the western flank of the Sierra Nevada, and the Klamath Mountains, where the lenticular beds sometimes attain a thickness of two thousand feet.

The Santa Lucia limestone, in the Coast Ranges, of doubtful Paleozoic age, also occur in large beds, amounting to several hundred feet in thickness, now changed to marble.

The Upper Triassic of Shasta and Plumas counties has lenses of limestone in places four or five hundred feet thick, forming important topographic features, and largely formed by the agency of corals.

The Franciscan series of the Coast Ranges has similar limestone masses of lenticular form, amounting in places to a few hundred feet in thickness, and wholly destitute of fossils, except a few traces of foraminifers.

The Cretaceous lacks limestone beds, except a local accumulation of shell limestone in the Knoxville formation of Colusa County, where a thickness of only a few feet is developed.

The Eocene of the Santa Cruz Mountains has some thin beds of limestone, and the Miocene of Santa Barbara, San Luis Obispo, and Orange counties has shell limestone amounting to as much as fifty feet in thickness. With the exception of these local occurrences there are no limestone masses in the marine beds of California from the middle of the Jurassic to the Quaternary, the Jurassic and Knoxville being characterized by thick beds of shale, and the other formations, from the Horsetown up, by enormous beds of sandstone.

Siliceous organic sediments.—Among the most remarkable features of the stratigraphy of California are the thick beds of siliceous organic sediments. In the Monterey shale of the Middle Tertiary in the Coast Ranges such sediments are extensively developed, and in places reach a thickness of five thousand feet. These are not shales in the ordinary sense, for they are chiefly organic in origin, the remains of microscopic diatoms and radiolaria. Similar deposits are known also in the Eocene of the middle Coast Ranges, but on a smaller scale. These organic siliceous shales are of great economic importance, for they have furnished nearly all of the petroleum of California.

Similar masses of siliceous organic sediments are known in the Coast Ranges in the Franciscan formation, of the earlier Mesozoic, but they are no longer shales, rather hard, flinty rocks, with the organic matter long since removed, and the fossil tests of radiolaria almost entirely destroyed, so that the rocks now show little resemblance to organic sediments.

In the Mother Lode region of the Sierra Nevada there are somewhat similar chert masses, in beds supposed to be Jurassic in age. These too are probably of radiolarian origin. In the Middle Triassic of Shasta County a series of siliceous shales almost without sand grains, and about two thousand feet thick, likewise was probably formed partly from the shells of siliceous organisms.

The Lower Carboniferous and the Devonian of Shasta and Siskiyou counties also contain many hundreds of feet of fine-grained so-called siliceous shales that are probably, at least in part, metamorphosed organic sediments. Shells of diatoms and radiolaria are extremely rare in all these older beds, but organic silica is very soluble, and even a slight degree of metamorphism destroys the delicate tests, and thus obliterates the evidence of their origin.

Coal deposits.—During the Eocene epoch plant remains accumulated to a considerable extent in the swamps of the old embayment of California, especially along the western flank of the Sierra Nevada near Ione, the Coast Range island area of the Mt. Diablo region, and in the middle Coast Ranges of Monterey, San Benito, and Fresno counties. These leaf beds have since been compacted into lignite, and in a few places into true coal.

Chemical deposits.—In Kern, San Bernardino, San Diego, and Inyo counties there are extensive chemical precipitates of salt, soda, borax, and gypsum, concentrates from the old lakes and salt pans of the arid region, from Tertiary up to the present. The areal extent is not large, but they are scattered over enormous stretches of country, and are of great present or prospective economic importance.

Comparative Rate of Formation of Calcareous and Arenaceous Sediments

Most estimates of the relative rate of formation of calcareous and arenaceous sediments are merely conjectural. A method is here suggested by which a somewhat more reliable estimate may be made. It is based on the comparative thickness of a single formation in the Californian region with that of the same formation in another region. This can be reliable only when the entire formation is represented in both regions compared, and when the conditions are reversed. We have two such cases in the Carboniferous of California and the western

part of the Mississippi Valley region, and in the Cretaceous of the same regions.

The McCloud limestone of California represents nearly the whole Coal Measures, with only a small part of the upper division absent, and it is all rather pure limestone with a thickness of about two thousand feet. The Coal Measures section of Arkansas embraces all but the uppermost part of the formation, and the thickness is approximately twenty thousand feet, if we leave out the Poteau group, which is probably higher than the top of the McCloud limestone of California. This would indicate that it takes approximately ten times as long for a foot of limestone to form as it does for a foot of sandstone.

A similar conclusion may be drawn from a comparison of the Cretaceous sections of the two regions; and here the West Coast has an arenaceous section, while the Cretaceous rocks of the Southwest are in places entirely calcareous, a reversal of conditions from those of the Carboniferous.

The Cretaceous section of northern California shows a thickness of about thirty thousand feet, all sandy, and evidently deposited in shallow water in a synclinal trough, just as was the Coal Measures sandstone of Arkansas and Oklahoma. The Cretaceous beds of the Southwest, ordinary marls and chalky limestones, have, where not mixed with sandy deposits, a thickness of about three thousand feet. This again indicates that it takes about ten times as long for the accumulation of a foot of limestone to accumulate under ordinary conditions as it does for a foot of sandstone.

Of course the thicknesses vary in different parts of the same region, and at best are only rough estimates; also we cannot be sure in widely separated regions whether we have exactly the same geologic units represented in the sections compared. Also it is not at all likely that all limestones or all sandstones are laid down at even approximately the same rates. Still the agreement of the figures is too great to be accidental.

If we accept this ratio of ten to one for rates of formation of sandstone and limestone, we have a means of estimating the relative length of time consumed in laying down the rocks of the various formations, even when their lithologic character is different. Thus

the Triassic of the Great Basin region, with only four thousand feet of calcareous sediments, probably represents at least one-third longer time than the Cretaceous of California, with its thirty thousand feet of sandy beds. The Tertiary formations of California, which are about fifteen thousand feet thick, represent about one-half the time of the Cretaceous, which is twice as thick, and about one-third of the time of the Triassic of this region, which is hardly one-fourth as thick. The other formations are too incompletely developed here, or too varied in composition, for any reliable estimate of their relative length of time to be made. The Carboniferous section is complete, but has sandstones, shales, limestones, and tuffs alternating in such a manner that, with our present knowledge, it is hardly possible to estimate the entire system in terms of limestone.

NEOCENE FORMATIONS OF CALIFORNIA

Because of the numerous formations that have been named in the Tertiary of California, and the numerous changes that have recently been made in the nomenclature and succession of these formations, a detailed table is here added, for the sake of those interested in West Coast geology, and not familiar with its details.

The great development of petroleum in California and the intense activity of geologists in that field are responsible for the embarrassing wealth of formational names in the Neocene. They are necessary, at present, for it is a difficult matter to correlate the minor horizons with accuracy over such a large region.

Quaternary			Faunal Zone	San Diego	
Pliocene	Upper	Merced	Zone of Scutella interlineata		
	Lower	San Diego	Zone of Pecten healeyi	San Diego	Sandstones with Pecten healeyi and Pecten hemphilli Type section
Miocene	Upper	San Pablo	Zone of Pecten wattsi and P. coalingaensis	Carrizo formation	Sandstones with Pecten carrizoensis and P. cerrosensis
			Zone of Pecten oweni		
	Middle	Santa Margarita	Zone of Pecten estrellanus and Trophon carisaensis		
			Zone of Tamiosoma and Ostrea titan		
			Zone of Pecten discus		
		Monterey			
	Lower	Vaqueros	Zone of Agasoma and Pecten andersoni		
			Zone of Pecten magnolia and Turritella inezana		

	Los Angeles		Ventura		Santa Barbara		
	Fernando formation	Upper Fernando Deadman Island beds with Pecten caurinus	Fernando formation		Fernando formation	Upper Fernando with Pecten bellus	
		Middle Fernando with Pecten hemphilli		Middle Fernando with Pecten healeyi		Middle Fernando	
		Lower Fernando		Lower Fernando with San Pablo fauna		Lower Fernando	
						Pecten discus beds	
	Puente shales	Diatomaceous shales resembling the Monterey	Modelo formation	Flinty shales resembling the Monterey	Monterey	Diatomaceous shales, resembling the Monterey	Monterey
	Puente sandstone	Sandstones with fauna like that of the Ocoya formation		Barren sandstones			Ocoya Creek beds
	Vaqueros	Sandstones with Turritella inezana	Vaqueros	Sandstones with Turritella inezana and Mytilus mathewsoni	Vaqueros	Sandstones with Turritella inezana and Pecten magnolia	

NEOCENE SECTIONS OF CALIFORNIA

Ventura	Santa Barbara		Kern		Coalinga		San Luis	
	Fernando formation	Upper Fernando with Pecten bellus			Tulare	Lake beds with Pliocene fauna with some brackish-water beds	Paso Robles	Type Paso suppos freshw
Middle Fernando with Pecten healeyi		Middle Fernando			Etchegoin formation	Beds with Pecten wattsi and P. coalingaensis	Pismo formation?	Doubtfu to this It ma equival Santa
Lower Fernando with San Pablo fauna		Lower Fernando						
					Coalinga formation	Jacalitos beds with Pecten oweni	Santa Margarita	Typical with O Tam grega Pecten
		Pecten discus beds				Beds with Tamiosoma gregaria, Ostrea titan, and Pecten estrellanus		Pecten
Flinty shales resembling the Monterey	Monterey	Diatomaceous shales, resembling the Monterey	Monterey	Bituminous shales		Doubtfully referred to the Monterey	Monterey	Diato shales typical
Barren sandstones			Ocoya Creek beds	Barker's ranch beds with Agasoma barkerianum Agasoma kernianum and Pecten andersoni	Temblor	Type section of Temblor, with fauna like that of the Ocoya Creek formation	Temblor	Sandst Agasom Turritel and math
Sandstones with Turritella inezana and Mytilus mathew-soni	Vaqueros	Sandstones with Turritella inezana and Pecten magnolia			Vaqueros		Vaqueros	Massive Turritel Pecten Mytilus

a Luis Obispo	Salinas Valley		Santa Cruz			Mt. Diablo Region	
Type section of Paso Robles, upposed to be of reshwater origin	Paso Robles	Gravels like those of the type section	Merced	Marine beds of Lake Merced and freshwater beds of Santa Clara	Santa Clara	Berkleyan	Freshwater Pliocene and Miocene of the Berkeley Hills
oubtfully referred to this horizon. It may be the quivalent of the Santa Margarita	Etchegoin	Sandstones with Scutella gibbsi and Pecten wattsi	Purisima	Marine beds of Half Moon Bay with Pecten healeyi		San Pablo	Type section on San Pablo Bay with Pecten pabloensis and Astrodapsis tumidus
ypical sandstones ith Ostrea titan Tamiosoma gregaria, and ecten estrellanus	Santa Margarita	Type section of Santa Margarita with Ostrea titan Tamiosoma gregaria and Pecten estrellanus	Santa Margarita	Sandstones with Ostrea titan and Astrodapsis antiselli		Santa Margarita	Kirker's Pass beds with Santa Margarita fauna
							Sandstones with Ostrea titan and Pecten crassicardo
ecten discus beds		Pecten discus beds					
Diatomaceous shales, like the ypical Monterey	Monterey	Type section of Monterey shale	Monterey	Bituminous diatomaceous shale		Monterey	Monterey shale
andstones with gasoma gravidum urritella ocoyana and Mytilus mathewsoni			Temblor	Sandstones with Agasoma gravidum Turritella ocoyana and Pecten andersoni		Contra Costa	Sandstones with Agasoma and Turritella ocoyana
assive sandstones with urritella inezana ecten magnolia and tilus mathewsoni	Vaqueros	Type section of Vaqueros, massive sandstones of the Santa Lucia Mts. with Turritella inezana	Vaqueros	Sandstones with Turritella inezana			

SYNOPSIS OF QUATERNARY HISTORY OF CALIFORNIA

RECENT	Subsidence epoch of Golden Gate and other bays		Invasion of Golden Gate River System by tide water and formation of the harbors of the West Coast. This subsidence has been going on until very recent time, for Indian shell mounds around the Bay of San Francisco are partly flooded			
QUATERNARY	Terrace epoch	Terrace	Period of uplift and scouring out the channels filled during the San Pedro epoch, forming terraces in the fluviatile sediments of San Benito Valley, and nearly all the valleys of the Coast Range. The youngest (lowest) terraces of the San Pedro truncate the upper San Pedro beds and are later than they. The older (higher) wave-cut terraces of the West Coast probably date back to the Sierran epoch			
	Upper San Pedro	Champlain	Epoch of depression along the coast	Warm water marine fauna	Epoch of filling pre-existing valleys with gravels and other fluviatile sediments. Seen in the Salinas Valley, Santa Clara Valley, San Benito Valley, and the Great Valley	
	Lower San Pedro		Coast stood 300–700 ft. lower than now	Cold water marine fauna		
	Sierran epoch. Probably longer than all the rest of the Quaternary	Glacial	Period of elevation of the West Coast, forming the great canyons off the Sierras and the submerged canyons of the coast. A period of no marine sediments (now exposed). In part contemporaneous with the Glacial epoch, for the glaciers of the Sierra Nevada came down some of the Canyons. The West Coast then stood about 3,000 ft. higher than now, as shown by the submerged Monterey Bay Canyon at a depth of 3,000 ft.		The principal terracing along the coast took place at this time, and also the Channel Islands were connected with the mainland, as shown by the Santa Rosa Mammoth	
		Pre-Glacial				
PLIOCENE	Merced Beds		Period of depression and filling of troughs with marine Pliocene sediments, and formation of great Pliocene lakes above sea-level			

THE APPALACHIAN FOLDS OF CENTRAL PENNSYLVANIA

ROLLIN T. CHAMBERLIN

The observational basis of this study of the Appalachian folding in central Pennsylvania was laid during a special trip on foot from Tyrone to Harrisburg during the summer of 1905. The chief purpose was to measure the dip-angles of the strata at as many stations as possible, that they might be subsequently plotted to scale as a groundwork for restoring the folded structure. Nearly 400 dips were measured, but on plotting them and attempting to restore the structure it was found that they only scantily covered several portions of the section where critical data were especially desirable. This proved to be particularly true of the neighborhood of Harrisburg, where the anticlinal arches are overturned and the shales and slates are so crumpled that, with the time available, it was not possible to trace out many of the minor, but none the less important, complications of structure. As a result it was felt that the material at hand was scarcely adequate for a serious study, and in the hope that a later opportunity might arise to make a further search for the desired data, the work was laid aside. But up to the present no opportunity to again visit this region has presented itself and it has seemed, on reflection, best to proceed with the original purpose, since this was not so much to gain a truer view of this particular case of folding, as to put to working trial certain recent suggestions as to the deductions that may be drawn from data of this sort. In Chamberlin and Salisbury's *Geology*, Vol. II, pp. 125–126, a method is given for deducing the thickness of the shell involved in folding. The present study is a preliminary attempt to make a special application of this method and to see what collateral suggestions might spring from it in practice. For this purpose it is not so material, though it is desirable, that the actual data be complete. In the very nature of the case, most studies of this class must, for the present, deal with incomplete data, since

each case has certain indeterminable factors. The necessary deficiencies, however, only make the more serviceable any deductions that can be drawn from such data as are available, if they can be so handled as to extend their significance. It has seemed possible therefore that a discussion based on data that have even serious shortcomings may have some value. It is only because it is hoped that this might prove true that it has been decided to carry out these studies on the present observational data.

The tract of the Appalachian Mountains most readily accessible for dip studies is that which lies along the main line of the Pennsylvania Railroad between Tyrone, in Blair County, and Harrisburg. From Tyrone to Mount Union the railroad, following the Juniata River, crosses the folds in a fairly straight line at right angles to their strike and affords a very good section. But just beyond Mount Union the Juniata turns sharply to the northeast and runs for twenty-five miles parallel to the strike, as far as Lewistown. This offset necessitates a division of the whole cross-section into two parts. From Lewistown to Harrisburg the folds are crossed generally at right angles to the strike with the exception of a few minor curves. This constitutes the second portion. Inasmuch as the second portion commences near Lewistown at the point corresponding to that where the first section left off near Mount Union, it would seem that no great structural error is introduced by ignoring the shift and uniting the two separate parts into one section.

At every available rock-outcrop along each of these lines, the dip of the strata was read with a clinometer compass, using the telegraph poles which are set thirty-eight to the mile as a means of locating the stations. For rapid work of this sort the spacing of the telegraph poles may be used so as to give quite closely the distance intervening between the locations of outcrops. Allowance, of course, must be made whenever the railway-line crosses the folded structure obliquely and curvingly, instead of normal to the strike. Wherever there occurred sudden changes in the angle of dip, or small local folds, diagrammatic sketches were made of the rock-face, and on these sketches the clinometer readings were recorded at the appropriate points. Where there were good outcrops the details of the folded structure were readily discerned, but unfortunately there were

frequently considerable areas over which suitable rock-exposures were wanting. In all, nearly four hundred dip-angles were recorded between the nearly horizontally bedded uplands west of Tyrone and the outskirts of Harrisburg.

In plotting the dip-angles to scale on co-ordinate paper, it was found most convenient to represent the distance between two telegraph poles, or one thirty-eighth of a mile, by two millimeters, which was the smallest unit available on the style of paper used. Therefore each mile in nature is represented by seventy-six millimeters on paper. From these plotted dip-angles and the available information upon the location of the contacts of the different formations and their varying thickness, partly obtained in the field and partly from the reports of the Pennsylvania State Survey, the writer has attempted to restore the complete folded section as it is supposed to have been before the ridges were truncated by erosion. Necessarily the uncertainties in the projection of folds are so considerable that this can be regarded only as a rough approximation to the original conditions following the period of folding. It is on the basis of this restored section that the present study has been made.[1]

THE SHORTENING OF THE CRUST

Several estimates of the amount of crustal shortening involved in the folding of these mountains have already been made. Lesley placed the lateral movement of the Appalachian thrusting at forty miles.[2] Claypole[3] divided the folded tract into two parts; the first from the approximately horizontal formations on the northwest, across the eleven principal ranges of mountains to Blue Mountain on the southeast, a total of forty-nine miles; the second, sixteen miles in length, crosses only the Cumberland Valley. By deducting twenty miles of the first section for the flattish tops of the anticlinal crests and

[1] For an alternative profile of the Appalachian flexures, a series of dip-readings was made along the Susquehanna River between Harrisburg and the vicinity of Williamsport. But this proved to be a less representative section, and since, in addition, good outcrops were less numerous, only the Tyrone-Harrisburg section will be treated in this article.

[2] J. P. Lesley, cited by Chamberlin and Salisbury, *Geology*, Vol. II, p. 125.

[3] E. W. Claypole, "Pennsylvania before and after the Elevation of the Appalachian Mountains," *Am. Nat.*, Vol. XIX (1885), pp. 257–68.

the bottoms of the synclinal troughs, and assuming that the remaining twenty-nine miles of strata possessed an average dip of 40°, he arrived at the conclusion that these forty-nine miles of strata, if flattened out, would measure fifty-eight miles. It is not easy to determine the number of folds occurring in the Cumberland Valley, but on the basis of the thickness of strata included in these plications, Claypole reasoned that there could scarcely be less than eight overthrown anticlinal arches in the sixteen miles considered. Adopting Professor Rogers' lowest angle of dip for the southeast legs (45°) and 60°, his lowest estimate for the northwest limbs, he calculated that ninety-five miles of strata had been compressed into these sixteen miles. Considering both sections together, this would mean that a tract of the earth's surface measuring originally one hundred and fifty-three miles had been compressed into sixty-five miles. As Claypole frankly stated, this estimate took account only of the eleven principal folds and ignored the minor flexures.

The present estimate of crustal shortening is made from a measurement of the strata in the plotted cross-section formed as above stated and made to include as much as possible of the minor contortions of the beds. The data for these sections were obtained at the railroad horizon. From the dip-angles, the locations of the formation-contacts, and the thicknesses assigned to the formations, the whole series of beds up to the top of the Pottsville conglomerate were projected over the entire restored section. But as the youngest of these arched strata had to be projected many thousands of feet above the railroad-level to do this, it is to be noted that the farther up in the stratigraphic series the restoration of structure is carried, the more uncertain does it become. The separate strata, being of different material and offering varying resistance to the thrust, cannot always be supposed to wrinkle alike. Minor flexures and local bits of crumpling may fade out in passing up or down, and new ones appear. Hence for the purpose of measuring the length of strata over this section it seemed advisable to choose the stratigraphic horizon which remained nearest to the railway-level. It is to be recognized, of course, that the maximum amount of crustal shortening was probably suffered by the surface beds and that the folds slowly die out downward, but it is believed that whatever lessening of the flexures there may be in the

first few thousand feet would be likely to be more than offset by the probable error in projecting folds to such a distance from the observed dips.

For the division from Tyrone to Mount Union (Figs. 1 and 2) the thin, but strongly resistant Oriskany sandstone was chosen for

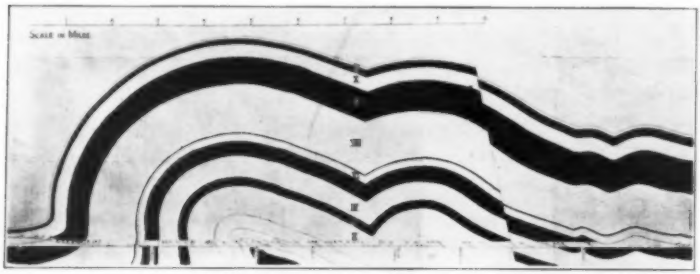

FIG. 1.—A reconstruction of the folded section from the essentially horizontally bedded uplands west of Tyrone nearly to Petersburg. East of Tyrone the dip-angles are plotted on the horizontal line which represents the railroad-level; on the uplands west of Tyrone they are plotted according to the surface topography. The numbers representing the formations are those used by the Pennsylvania Geological Survey: II, Trenton and Calciferous; III, Hudson River shales; IV, Oneida and Medina; V, Clinton; VI, Lower Helderberg; VII, Oriskany; VIII, Chemung; IX, Catskill; X, Pocono; XI, Mauch Chunk; XII, Pottsville conglomerate.

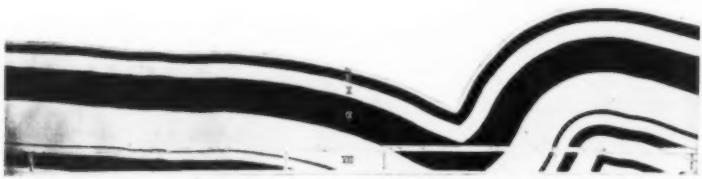

FIG. 2.—Continuation of section from Petersburg to Mount Union

measurement as likely to give the most reliable results. In the second section the Oriskany was also measured as far as the crest of the anticline just before the prominent fault near Iroquois Station (Fig. 4). At the very crest-point of this anticline the measurement was shifted from the Oriskany to the base of the Catskill since the strata soon take a tremendous dip which carries the Oriskany far below the surface. This shift appears permissible since the fold is approxi-

mately symmetrical. The measurement then followed the base of the Catskill to the end of the section (Fig. 5).

To follow and measure the contortions of these two selected formations throughout their length, a copper wire was used. Placed upon

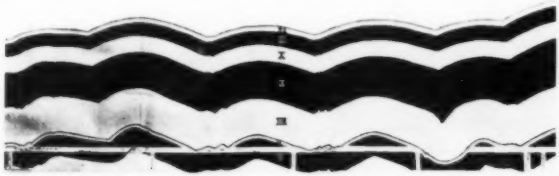

FIG. 3.—Reconstructed section between Lewistown and Durward

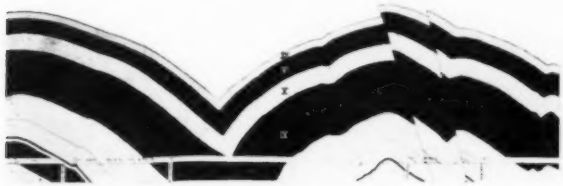

FIG. 4.—Section between Durward and Aqueduct Station

FIG. 5.—Continuation of section from Aqueduct Station to Harrisburg

the plotted cross-section, this was bent so as to be exactly superimposed upon the line to be measured. This wire, when straightened out and measured, represented very closely the length of the chosen stratum along its tortuous course. As the cross-sections were plotted on millimeter paper all measurements were made in that unit.

The total length of the Oriskany stratum as reconstructed in the cross-section from the west end of the folded region to Mount Union (Figs. 1 and 2) was found to measure 2,602 millimeters. The straight-line distance between these points measured on the railroad-level is 2,288 millimeters. The length of the top line of the restored section (the top of the Pottsville) was also measured as a check. It was found to be 2,618 millimeters. If 2,602 millimeters, the length of the Oriskany along the dip, represents the original length of that stratum before the folding took place, and 2,288 millimeters represents the present horizontal length of the section under consideration, there must have been a shortening of this formation to the extent of 314 millimeters, or 12 per cent. of the original length. On the scale used, seventy-six millimeters in the cross-section represents one mile in nature. Converting the figures obtained from a measurement of the plotted section into miles, the length of the Oriskany (2,602 millimeters) becomes 34.2 miles and the horizontal distance, 2,288 millimeters, is equivalent to 30.1 miles. Neglecting other factors, the shortening amounts, therefore, to 4.1 miles.

In the second section the length of the Oriskany from the beginning at Lewistown to the crest-point of the anticline above mentioned between Baileysburg and Iroquois Station was found to measure 1,789 millimeters. At this point the shift was made to the base of the Catskill. The lower limit of this formation, followed to the point where it rises above the railroad-level about half a mile southeast of Marysville, gave a dip distance of 1,070 millimeters. The sum of these two dip measurements gives 2,859 millimeters as the length of these strata between Lewistown and the contact of the Catskill with the Chemung close to the Susquehanna bridge five miles above Harrisburg. On the same scale the present horizontal distance between these points is 2,399 millimeters. This indicates a crustal shortening due to the flexing of the beds, which amounts to 460 millimeters, or 16.1 per cent. of the original length. Translated into miles these figures are respectively 37.6 and 31.5 miles, signifying a shortening of 6.1 miles. The total shortening, therefore, from the beginning of the section west of Tyrone to the point between Marysville and the Susquehanna bridge amounts, on the basis of the assumptions made, to 10.2 miles, 71.8 miles having been compressed to 61.6 miles.

Southeast of the Susquehanna bridge above Harrisburg the data obtained were inadequate and unsatisfactory. The strata to which we must look for guidance here are Hudson River shales and slates, and they are mashed and disturbed to such an extent that often there is danger of mistaking secondary structures for bedding. Wherever observed these beds all dip southeastward at angles varying from 50°–80° in such a way as to indicate overturned folds. But these soft shales furnish the poorest sort of criterion for determining the true character of the folding, because a weak formation of this sort may be much wrinkled, crushed, and appressed, while the stronger strata above may have been merely bowed upward and may not have suffered crumpling to the same extent. In projecting the younger formations over these folded shales, the wrinkles were made to die out slowly. The shale layers were allowed considerable thickening and thinning, but in the stronger layers above little of this distortion was taken into account. It may well be that considerably more thickening of the layers on the crests and troughs, and thinning on the limbs of the folds should be allowed in the upper formations. Since the observed data for this slate and shale belt are so meager and the restoration of the younger formations which once covered this region is so precarious because of this limited knowledge, and because the whole is so much a matter of personal opinion, it has not seemed advisable to state any measurements made upon the reconstructed curves. Some of the layers were measured, however, and upon this basis a rough guess that the original length of these strata was about twice their present horizontal length is ventured. They can scarcely have suffered much less shortening than this, though they may have suffered much more. Claypole believed that these overturned folds resulted from such intense crumpling that into each horizontal mile of present distance there have been squeezed what were originally six miles of flat-lying strata; but this figure seems to me somewhat excessive.

To put these figures together, we have, on the basis of the assumptions made, and subject to other limitations to be mentioned shortly, 71.8 miles reduced to 61.6 miles west of the Susquehanna bridge, and 9.5 miles jammed into the present distance of 4.75 miles between Harrisburg and the Susquehanna bridge, making a total west of Harrisburg of 81 miles compressed into 66 miles.

The various elaborate factors which enter into the problem of crustal movement, and which embarrass quantitative determinations of the shortening, have been ably discussed by Van Hise.[1] These embarrassing factors include the following: (1) The thickening and thinning of the strata in the different parts of the sharper folds. The thickening and thinning are uncertain variables, for which it is difficult to make allowance when only a very limited portion of the whole fold can be observed, as is usually the case. (2) The variation in the closeness of the folding in passing upward or downward from the layer on which the observations were made. The farther upward from the recorded data the folds must be projected, obviously the greater the error likely to creep in. It was for this reason that, in the case in hand, the measurements on the plotted section were made along those strata which departed the least from the railroad horizon. (3) Subsequent relaxation of the strata under the influence of gravity. This may take the form of gliding on the limbs of the folds where a new series of corrugations may be developed; it may also be manifested in the opening of fissures and in the phenomena of normal faulting. The effect of these secondary phenomena involving dilatation of the surface shell subsequent to the folding period is to cause an overestimate of the extent of the crustal shortening. But the quantitative importance of gravity wrinkling in the Appalachian region arising from relaxation and creep since the period of folding is, for the present at least, impossible of determination, but it is probably not seriously large.

It is also probable, on the whole, that in addition to the folding the lateral thrusts have caused a certain amount of mashing and compacting of the material of the beds. A few measurements upon the wax-and-plaster folds developed experimentally by Willis[2] show that the decrease in the length of the layers due to mashing alone, varied from 1 up to 10 per cent. of the original length. The total shortening of all kinds in the illustrations selected for measurement varied from about 15 per cent. to somewhat more than 60 per cent.

[1] C. R. Van Hise, "Estimates and Causes of Crustal Shortening," *Jour. of Geol.*, Vol. VI (1898), pp. 10–64.

[2] Bailey Willis, "The Mechanics of Appalachian Structure," *Thirteenth Ann. Rept., U.S. Geol. Surv.* (1891–92), Pt. II, pp. 211–82.

The variation in the amount of linear reduction due to mashing appears to correspond to differences in the character of the material used in the experiments. As a rule the softer the material in the layers the greater the degree of mashing; when more plaster and less wax and turpentine stiffened the layers, they were much less compacted. An average figure for the shortening of the layers due to mashing in these experiments by Willis would seem to lie in the neighborhood of 5 per cent. In the case of the Appalachians, however, the amount to be allowed for shortening due to mashing of the strata in addition to that resulting from the corrugation must be left largely to conjecture, but as the rock-formations are relatively much stiffer than the wax-and-plaster layers used in the experiments, it would seem likely that the figure for the mountains should be considerably less than 5 per cent.

Tending to offset the shortening due to the mashing of the rocks is the subsequent elongation of the strata arising from the opening of fissures, jointing, cementation by infiltration, and the penetration of igneous intrusions. Several former fissures near the junction of the Juniata with the Susquehanna have been rendered conspicuous by the intrusion of Mesozoic trappean magmas which have solidified within them. No attempt at any quantitative estimate of their importance in crustal shortening is made here. Whether the importance of these various secondary factors is material and whether, if ignored, the balance of their sum-total tends toward an overestimate, or an underestimate, of the true extent of the crustal shortening, is here left to the individual judgment of each geologist guided by his own experience and insight. The results reached later may have some reflex bearings on these points.

THE HEIGHT OF THE FOLDED TRACT

For a study of the dynamics of crustal warping and the nature and dimension of the mountain-building movements, one of the necessary factors to be determined is the amount of vertical bulging. To determine the extent of the upswelling connected with the folding it is necessary to measure the height of the newly folded ranges above the average height of the same region before the movements began. The first requirement is a base plain to which may be referred the

attitude of the land surface before the folding took place; the second requirement is a visible base-line available at the present day, above which the projection of the folded tract is to be measured. In view of the fact that the critical period of folding occurred as far back in geologic history as the close of the Paleozoic, and in view of the still more compromising fact that other diastrophic movements have disturbed the Appalachian belt since that time, it might at first seem that such planes of reference could not reasonably be hoped for. But fortunately the physiographic history of the Appalachians has been admirably arranged to meet the requirements of the case.

The last beds to be deposited in the present mountain tract were the upper strata of the Coal Measures. From the nature of these beds, particularly the persistence of coal repeated in a considerable number of separate seams over adjacent areas of wide extent, it is confidently inferred that the Appalachian region during the Upper Carboniferous must have constituted an almost perfect plain of sedimentation, at times just at, or a few feet above, the sea-level, and at other times but slightly submerged. The very considerable areas over which individual coal-seams may be traced testify to the uniformly level condition of the region. It was this rather remarkable plain of sedimentation, warped and wrinkled by the throes of the dying Paleozoic, that rose into the great Appalachian plications.

On the other hand, the mountains thus formed had their day and were gone before the end of the Mesozoic, when a new plain had been established. The Kittatinny base-level, strikingly visible even today in the level crest-lines of all the major ridges of this portion of Pennsylvania, shows that by the close of the Cretaceous, the former mountain tract had been beveled till the land again stood close to the sea-level.

Thus the Appalachian region started approximately from the sea-level, was thrust up into tremendous folds, and then planed down by erosion again essentially to the level of the sea. If no other diastrophic movements intervened to complicate the case, the total upwarping of the crust should be expressed by the average height of the freshly folded tract above the sea, and if the height of the sea relative to the land of this area remained the same till the Kittatinny base-plain was established, that plain should constitute an absolute

base above which the hypothetically restored folded section could be measured. But the sea-level undoubtedly did not remain stationary through such a long period of time. Such a ponderous series of mountain-masses must have been subject to some settling. Possibly a mathematical analysis of the mechanics involved might furnish a theoretical figure for the possible isostatic changes, but the problem is quite beyond the reach of the present paper.

Some rise of ocean-level is also to be expected on account of the filling of the ocean-basin with the material removed from the mountains in the process of peneplanation, and obviously sedimentation in other portions of the oceanic area would be equally effective in changing the water-level; and hence the great ramification of the problem.

Some crustal warping also appears to have occurred at the east during the early Mesozoic. The Newark series of sediments, which were laid down in local depressions in southeastern Pennsylvania during the Triassic, seem to imply a certain amount of downwarping in that region.[1] Later, at the close of the Triassic, or early in the Jurassic, the deposition was stopped by the reversal of the conditions which started it.[2] A moderate elevation with tilting affected the Newark beds. But to what extent these warpings in the eastern part of the state affected the mountain-section under consideration is uncertain, and whether the sum-total of the movements should be regarded as upward or downward must remain, for the present, largely a matter of conjecture.

But in general the period of erosion and base-leveling which was inaugurated by the mountain-building at the close of the Paleozoic and which resulted in the Kittatinny plain was one of comparative quiescence and, on account of its freedom from the more important dynamic movements, the present case is probably as favorable as any other which could be selected.

It will therefore be assumed that when the folding commenced the formations were practically horizontal and the upper surface of the youngest beds essentially at sea-level. It will also be assumed that the Kittatinny base-plain in turn represents somewhat approxi-

[1] Chamberlin and Salisbury, *Geology*, Vol. III, pp. 7–9.

[2] W. M. Davis, "The Rivers and Valleys of Pennsylvania," *Nat. Geog. Mag.*, Vol. I (1889), p. 196.

mately a horizon equivalent to the sea-level from which the strata were upwarped. Estimates of the height of the folded tract may therefore be measured from the Kittatinny plain as a base. In this way the Tertiary uplifts and any other disturbing factors since the Cretaceous are eliminated.

In the reconstructed section no beds younger than the Pottsville conglomerate were included, for the reason that no younger formations now occur in the region studied. It seems highly probable, however, that the Allegheny, Conemaugh, Monongahela, and possibly the Dunkard formations once covered this portion of the Appalachians, and were incorporated in the folds but have since been removed by erosion. These formations vary considerably in thickness in different localities. In Westmoreland County the Lower Productive, Lower Barren, Upper Productive, and Upper Barren Measures have a total thickness of 1,477 feet.[1] Campbell gives 1,540 feet for the Coal Measures above the Pottsville in southwestern Pennsylvania.[2] These are on the southwest side of the area under consideration; in the anthracite regions to the northeast, the Coal Measures appear to be thicker—in the northern field 1,800 feet, in the middle 1,500 feet, while they attain a total aggregate of 2,500 feet in the southern field, and it is not certain that some layers may not have been removed by erosion from each of these districts.[3] The thickness of these formations over the Tyrone-Harrisburg mountain-section was perhaps of about the same order of magnitude, though this must always remain a matter of conjecture. A belt representing the missing Coal Measures therefore belongs above the Pottsville, but was omitted from the cross-sections because of the uncertainty as to the thickness and former extent of these beds. An average figure for the thickness of these missing beds is to be added to the height of the folded section in the following estimates.

But the Kittatinny base-level maintains also somewhat fluctuating elevations above the railroad tracks. Generally about 1,000 or 1,100 feet separate the two horizons, but at points in Huntingdon

[1] J. J. Stevenson, *Second Geol. Surv. Pennsylvania*, 1876, Fayette and Westmoreland Districts.

[2] M. R. Campbell, *Masonville-Uniontville Folio*, U.S. Geol. Surv.

[3] Penn. Geol. Surv., *Summary Final Rept.*, 1895, Vol. III, Part 1, "Carboniferous," p. 1924.

County the peneplain rises to approximately 1,500 feet above the railroad. As the measurements were all made from the railroad, this correction for the height of the Kittatinny base-level above it should be subtracted from the total height of the folds. Here then are two corrections of opposite sorts, one positive and the other negative. While the figure for the positive correction would seem likely to be somewhat in excess of the figure to be subtracted, there is no good basis for close figuring, and the safest thing, on the whole, seems to be to allow the present height of the peneplain above the railroad which served as a base-line for collecting the data and constructing the cross-section, to offset what younger strata there may have been above the Pottsville conglomerate. Measuring then from the railroad-level, at which the data were collected, to the top of the Pottsville should give, perhaps, as good an approximation to the height of the original folds as a similar measurement from the Kittatinny peneplain to the more uncertain upper surface of the Upper Barren Measures. These more convenient and readily available measuring-points will therefore be taken.

If, however, one should prefer to strike a general average for the thickness of these measures over the various neighboring areas where they now occur, and to assume that this full thickness of strata covered the whole extent of the Tyrone-Harrisburg section, he may readily do so. From the data given by Stevenson,[1] a figure of 1,700–1,800 feet would seem a fair one to adopt. If 1,100 feet represents the average difference in altitude between the Pennsylvania Railroad and the Kittatinny base-level, there remain, following this assumption, 600–700 feet to be added to the estimate of the height of the folded tract to be made shortly. But it is not at all certain that this full thickness of post-Pottsville sediments once extended completely over this area, and, in addition, it would seem that the thicknesses of the various Paleozoics in the reconstructed sections are more likely to be overestimates than underestimates. Because of a suspicion that possibly somewhat excessive thicknesses may have been allowed for some of the restored formations in the section, the writer prefers not to add this last correction to the total height of the folded belt.

[1] J. J. Stevenson, "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 65–228, and Vol. XVIII, pp. 29–178.

To determine their average vertical dimension, the cross-sections were photographed and the glazed-paper prints carefully cut at the railroad-level as base-line, and the top of the Pottsville conglomerate as the sky-line, and the resulting paper equivalents of the sections then weighed on delicate balances. At the same time similar strips of duplicate prints, cut to represent a uniform height of one mile of strata above the base-line, were also weighed. Thus weighed in the five separate sections, the results were:

	Grams
Section 1 weighed	0.4819
Scale representing same area weighed, per mile of height	0.1394
Hence average height of reconstructed beds of Section 1 is 0.4819/0.1394=3.45 miles.	
Section 2 weighed	0.4346
Scale representing strata uniformly 1 mile thick for this distance weighed	0.1833
Hence average height of reconstructed beds of Section 2 is 0.4346/0.1833=2.37 miles.	
Section 3 weighed	0.4231
Scale representing 1 mile of strata over this area weighed	0.1466
Hence average height of reconstructed beds of Section 3 is 0.4231/0.1466=2.88 miles.	
Section 4 weighed	0.3981
Scale for this distance weighed	0.1466
Hence average height of reconstructed beds of Section 4 is 0.3981/0.1466=2.71 miles.	
Section 5 weighed	0.5402
Scale for this distance weighed	0.1466
Hence average height of reconstructed beds of Section 5 is 0.5402/0.1466=3.68 miles.	

The general average height of the strata over the last four sections can be obtained directly by dividing the sum of the weights of the four paper sections by the total weight per mile of elevation of the corresponding scales.

	Grams
Total weight of Sections 2, 3, 4, and 5	1.7960
Total weight of corresponding unit mile scales	0.6231
Average height for these sections, 2.88 miles.	

Section 1 cannot be averaged in thus, as it was photographed on a slightly different scale. But the length of Section 1 on the original

plat is 1,139 millimeters, while the total length of the other four sections is 3,910 millimeters.

Therefore $\frac{(3.45\times1139)+(2.88\times3910)}{1139+3910}=3.01$ miles, the average height of the top of the restored Pottsville conglomerate over the area from Tyrone to Harrisburg.

This figure of 3 miles applies to the whole distance plotted. For the purpose of study it was also desirable to know the average height of the folded tract for the section from Tyrone only to the Catskill-Chemung contact just southeast of Marysville. The photo print of Section 5 was therefore carefully cut at this point and the northwestern portion placed on the balance. This portion weighed 0.2100 grams, while Section 5 originally weighed 0.5402 grams. This northwestern portion of Section 5 measured 559 millimeters on the large plot compared with 921 millimeters linear measurement for the whole of Section 5. Calculated on this basis the average original height of the Pottsville conglomerate from Tyrone to Marysville comes out 2.80 miles.

THICKNESS OF THE FOLDED SHELL

If one knows the average height to which the freshly folded tract was elevated, together with the amount of lateral shortening which has caused this elevation, it is a simple matter to calculate the thickness of the shell which suffered folding, neglecting compression, etc. By using the figures just obtained—81 miles compressed into 66 miles with a resulting mean elevation of 3 miles—one might make an estimate of the average thickness of corrugated strata across the whole tract. But as the thickness of the wrinkled shell is liable to be variable, it is necessary, in order to ascertain the true significance of the thickness and its variability, to consider separately the several dissimilar parts which make up the section. The most elevated tracts were on the flanks of the mountain-belt, at the two ends of the section under consideration. In both of these the Trenton limestone comes to the surface at the present time. Between these two greatest upthrusts is a long tract of lesser elevation and less acute folding. To bring out the significance of these variations, the six sections into which the whole cross-section was cut will each be considered separately.

Section 1, comprising the great anticlinal east of Tyrone, was shortened from 17.8 miles to 14.9 miles, while the top of the Pottsville conglomerate was raised to a mean height of 3.45 miles. To produce this relation between shortening and elevation, a thickness of crust amounting to 17.7 miles must have been compressed, provided there were no increase in the density of the rocks.[1]

Section 2 was found to have been shortened from 16.3 miles to 15.2 miles. As this block was raised 2.37 miles on the average by this folding, it must have had an original thickness of approximately 32.7 miles, on the assumption, of course, that the same degree of shortening persisted throughout the whole block.

Section 3 appears to have been reduced horizontally from 13.56 miles to 12.1 miles, and to have been elevated 2.88 miles. The same method of computation would assign to this block a thickness of 23.8 miles.

Section 4, which is now 12.1 miles in length, seems to have covered originally 14.44 miles. Having been upthrust to the extent of 2.71 miles, it should have a depth of 14.0 miles.

Section 5*a*, shortened from 9.6 into 7.37 miles and upthrust 2.36 miles, should constitute a block extending 7.8 miles below the measuring base.

Section 5*b*, the Cumberland County upswelling between the Susquehanna bridge and Harrisburg, rose to the extent of about 5.75 miles. I have assumed a shortening of two into one, or 9.5 miles reduced to 4.75 miles of horizontal distance. On this basis the thickness of the crust required would be only 5.75 miles, assuming uniform shortening throughout this thickness. If a greater amount of lateral compression be taken, the thickness of shell required becomes correspondingly diminished. Claypole, it will be remembered, assumed a shortening from 6 to 1 for the whole of the Cumberland Valley. On this assumption, provided the height of the folds remained the same, only about one mile of strata would need to be compressed to give the results.

[1] This method of dealing with the folded block takes no account, either of the possible increase in the density of the crumpled rocks, or of the possibility that there may have been some relief from the strains by down-folding as well as up-folding. But any changes in density must be slight, and any considerable down-folding against the great resistance of the underlying rocks seems improbable.

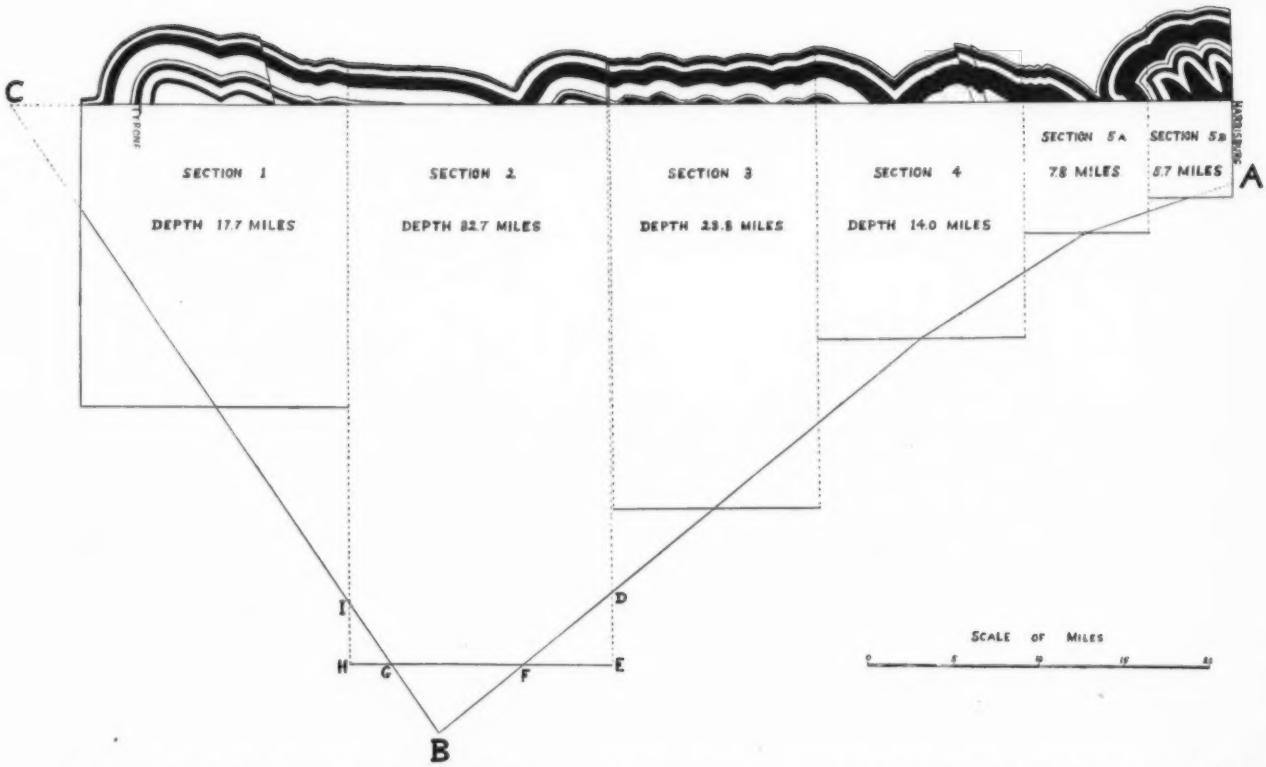

FIG. 6.—Plot of the Tyrone-Harrisburg folded section representing the thickness of deformed shell beneath each of the six blocks as developed by the above methods of measurement. The lines *AB* and *BC* are drawn through the middle points of the bottom lines of each of these blocks, except Section 2, the apex block. The triangle *GBF* is drawn equal in area to the sum of the triangles *GHI* and *DEF*. The whole deformed mass appears, subject to the necessary limitations, to be the triangular block *ABC*.

NATURE OF THE DEFORMED BLOCK

Fig. 6 expresses diagrammatically the variable thickness of the shell beneath the different sections of the folded tract, as developed by this method of analysis. The separate sections are each drawn to true scale as independent blocks, and constitute a series of steps. As the diagram rather strikingly shows, the folded shell is thinnest at the eastern end of the section and thence thickens step by step westward up to a certain turning-point, beyond which it shallows even more quickly. The regularity of these descending steps, when first worked out, came as a distinct surprise as it was not anticipated from the simple inspection of the reconstructed cross-section. It seems to be a feature of much significance and appears to give a concrete picture of how the deformation occurred.

In order to approximate more closely what may be supposed to have been the actual nature of the deformation, the broken lines *AB* and *BC* are drawn as substitutes for the artificial steps. These pass through the middle points of the bottom lines of each block with the exception of Section 2, the deepest segment, and hence the resulting sectional area of each segment remains essentially as it was in the rectangular block. Segment 2 is the apex, and to keep its area the same as the original block, the triangle *FBG* is constructed so as to equal in area the sum of the triangles *DEF* and *GHI*. At the same time Segments 1 and 3 retain their original areas.

Taken together the stepping-blocks from which the lines *AB* and *BC* have been derived are very suggestive. The thrust which produced these great mountain-flexures came presumably from the direction of the Atlantic Ocean. The near-by eastern side of the folded tract suffered more intense crumpling than the more remote western portion, the sharpest folding lying in the tract east of the present Blue Ridge. West of this the surface folds slowly die out with, however, one great fold at the west end. Simultaneously with the diminishing intensity of the folds, the thickness of the folded shell increases. Apparently the thrust from the Atlantic Ocean affected at first a moderately thin crust of five or six miles, or perhaps even less, which it squeezed intensely. From this thin, intensely compressed strip the lateral thrust was transmitted to the region lying immediately west; but instead of being communicated simply to the

upper five or six miles of strata, the strains appear to have diverged into an increasingly thick shell. In other words, the shear plane plunged downward. After reaching the maximum depth beneath Section 2, the limit of the deformed mass was deflected rapidly toward the surface. The deformed block thus assumed, in a general way, the form of a triangular prism.

That the analysis of field data should develop a deformed block of this shape and attitude was wholly unexpected but behavior of this sort is, in reality, entirely in accord with what the principles of mechanics imply for such bodies under lateral stress. In solid bodies under direct pressure, fracturing and shearing usually take place along the planes of greatest tangential stress. Becker has developed the application of this principle mathematically in the case of strained rocks. "A direct, uniformly distributed pressure of sufficient intensity, applied to an elastic brittle mass presenting great resistance to deformation, would induce fracture. The ruptures would take place along those lines subject to the greatest tangential strain, since these are the directions in which material would first be strained beyond endurance. These lines would stand at 45° to the line of force if the mass presented infinite resistance to deformation."[1] Hoskins in his analysis of strain and stress applied to the flow and fracture of rocks has also discussed this principle: "Simple sliding at any instance takes place along two sets of planes at right angles to each other and inclined 45° to the directions of elongation and shortening at that instant."[2] Leith's doctrine of fracture-cleavage is dependent upon the same principle and he agrees with Becker on the fundamental principle involved: "If fractures occur in irrotational strains, these follow intersecting planes approximately 45° to the greatest pressure—planes of greatest tangential stress."[3] The exact angle, however, varies somewhat with the nature of the substance and with the stress-conditions. In the Appalachians the greatest mountain-building pressure acted essentially horizontally. The planes of greatest tangential stress sho uld, therefore, dip at angles somewhere in the

[1] G. F. Becker, "Finite Homogeneous Strain, Flow and Rupture of Rocks," *Bull. Geol. Soc. Amer.*, Vol. IV (1893), p. 50.

[2] L. M. Hoskins, "Flow and Fracture of Rocks as Related to Structure," *Sixteenth Ann. Rept. U.S. Geol. Surv.* (1894–95), Pt. I, p. 865.

[3] C. K. Leith, "Rock Cleavage," *Bull. 239, U.S. Geol. Surv.* (1905), p. 121.

neighborhood of 45°, and may plunge downward or upward. Whatever fracturing or shearing there be, resulting from these lateral mountain-building thrusts, should follow these dipping-planes as lines of least resistance. If the mass under stress be prevented from undergoing relative motion in these directions, a much greater force would be necessary to compel it to move in any other direction.[1]

Perfectly in accord with these deductions and bearing directly upon the case under analysis, is the experimental work of Daubrée

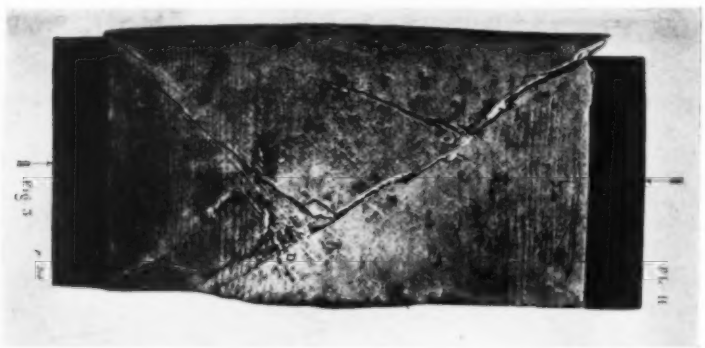

FIG. 7.—An experiment by Daubrée. The material of this prism was a carefully prepared mixture of plaster, wax, and resin, molded so as to be as nearly homogeneous as possible. When subjected to direct pressure at both ends, a wedge-shaped mass was fractured loose and lifted slightly out of its bed. Several systems of fractures have developed.

upon the problem of jointing. This brilliant experimenter subjected blocks of wax to direct pressure operating on the two opposite sides of the block. There were developed in this way two systems of fractures which were inclined to the direction of pressure at angles approximating 45°, and which, at the same time, bear a most striking resemblance to the Appalachian Mountain block *ABC* developed in Fig. 6. Fig. 7 is copied directly from one of Daubrée's plates.[2] The two figures form an instructive comparison; the one, developed from an analysis of data collected in the field without forecast of the result; the other, a photographic record of a direct experiment. In

[1] G. F. Becker, *op. cit.*, p. 47.

[2] A. Daubrée, *Etudes synthétiques de géologie expérimentale*, T. I, p. 316, Plate II, Fig. 3.

Daubrée's experiment a triangular prismatic mass has been fractured from the main block, and somewhat lifted. That it did not fold was no doubt due to the absence of adequate gravitative pressure. In the case of the earth-block the gravitative pressures at less than the block-depths exceeded the folding-strength of the strata and the wedge-shaped block deformed instead of simply rising *en masse*.

Both theoretical considerations and Daubrée's experiments show that angles of fracturing and shearing vary through a rather wide range, especially as the character of the material varies, and the correspondence of the Appalachian block to theory is perhaps closer than might be expected. In Fig. 6 the line *AB* in its deeper portion dips northwest at about 40°, while *BC*, as it is drawn, dips 54° southeast. In theory the fracture-dips in the upper horizons should normally be lower than 45° while the shear-dip in the lower, less brittle horizons, should be higher than 45°, and this seems to be exemplified in Fig. 6 and would no doubt be more strongly shown if the deformation had gone farther.

As previously stated, the greatest folds in this Pennsylvanian section lie at the two ends. The computed section in depth shows that these end portions are the thinnest and hence most susceptible to folding. The central portion descends far below the fracture-zone—and perhaps below the zone of typical folding—into the zone of quasi-flowage or plastic deformation, and this no doubt modifies the surface-deformation of this part.

At the western end the Tyrone fold seems to have been on the eve of passing into a fault when the movement ceased. Farther south faults of considerable throw have actually occurred in like positions at the inland border of the folded tract. In some parts of Tennessee the deformed belt is abruptly terminated on its western side by a sharp thrust-fault beyond which rest undisturbed horizontal beds.[1] The shell seems here to have been broken by a thrust analogous to that along *BC* in Fig. 6, and the deformed block thrust outward along the shearing-plane. The undisturbed strata lying just west of the fault indicate that the portion of the shell just outside of the disturbed block, on the west side, has not participated in the deformation. The deep plunge of the shear-plane near the western limit of the

[1] Briceville, *Tenn. Folio*, U.S. Geol. Surv

folded belt suggests that this deep insetting may constitute the mode by which the moving shell anchors itself in the less moving mass below and thus determines where the movement shall cease and the folding shall take place. This function I think is usually assigned to some specially stable portion of the earth-body. The plunge is here correlated with thick sedimentation and this may be an agency in inducing the plunge. If other cases shall support this suggestion it may offer a new view of the well-known relation between thick sedimentation and mountain-folding.

In Fig. 6 the line *BC* does not pass through the point where the strata were being shaped preparatory to faulting. This may be due to inaccuracies in the field work and in the reconstructed section. But Daubrée's experiment showed that there may be fracturing along several closely parallel lines near the edge of the moved block and that these may be broadly included in the accommodation zone. The angle *ABC* at the apex of the block is not far from a right angle. The fact that it is slightly less than 90° may be due perhaps to the fact that the triangular block has been laterally compressed, which would lessen the original angle at the apex, but such an explanation is not required as the variations of the angle natural to the case more than cover the departure from a right angle.

The likelihood of a zone of accommodation between the folded shell and the less movable interior where deformation by flowage is presumed to be the prevalent type, has been brought out in Chamberlin and Salisbury's *Geology*.[1] Near Harrisburg the moderately thin movable shell seems to have been so sharply crumpled that the adjustment between it and the solid support beneath would seem to have been accompanied by much shearing. But west of the Blue Ridge, where the folding was less intense and the compression was distributed through a much thicker segment, the adjustment between the more movable portion above and the less movable portion below may have been accomplished mainly by distributive shear. The flexures on the surface presumably pass downward into the zone of quasi-flowage where they accommodated themselves by distributive deformation.

Turning back from these details to the general problem of estimating the thickness of the folded shell, it may be recalled that the calculation commences with three dimensions obtained from the field

[1] Vol. II, p. 130.

studies, viz.: (1) the present horizontal distance across the folded section, (2) the original length of the same block before folding, and (3) the estimated average height to which the folded beds were thrust. Obviously the nature of the result obtained by this method of inspection is dependent upon the relation between the amount of crustal shortening and the height to which the beds have been raised in consequence of this shortening. Clearly, the greater the horizontal shortening of the folded block in proportion to the resulting vertical bulge, the thinner that block must be; and likewise, the less the horizontal shortening in proportion to the average height of upwarped beds, the thicker the deformed shell must be. In the Pennsylvania section considered, the less closely folded strata between the Blue Ridge and the western anticlinorium stood considerably higher in proportion to the amount of lateral shortening suffered than did the intensely folded beds to the east. Because of this, the calculations indicate a deformed shell increasing in depth to the maximum point beneath the slightly deformed region in Section 2 and thinning again beneath the anticline at the west end. These calculations, of course, assume that the folds have derived their height solely from the upthrusts of the crumpling process, and that the height of each particular area has been determined by the extent of the plication directly beneath it. If these assumptions are at variance with the facts, the conclusions are correspondingly at fault. The results, however, seem to imply that the assumptions are not seriously at fault.

For the sake of simplicity, it has been assumed that in these shortened blocks the amount of shortening deduced from the present surface beds has continued undiminished throughout the whole thickness of each block. But such uniformity is not to be expected since the thrusts of the upper and lower parts of the shell are probably not always the same and one mode of deformation doubtless grades into another. This complicating factor must lessen somewhat the significance of the numerical figures obtained, without however detracting seriously from the general nature of the results.

So far as a single test may go in justifying a method of inquiry, this trial of the suggested mode of determining the thickness of the shell involved in mountain-folding may be regarded as not only sustaining the value of the method, but as indicating forms of application whose values were not anticipated.

THE EVIDENCE OF THE FLORA REGARDING THE AGE OF THE RARITAN FORMATION

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Since it has been supposed by some invertebrate paleontologists that the Atlantic and Eastern Gulf Cretaceous above the Patapsco formation of the Maryland-Virginia area is all of post-Colorado age, i.e., Senonian by European standards, and since the faunas are for the most part poorly preserved and but partially studied, and furthermore since the physical conditions were more uniform than in the great plains area as indicated by the character of the sediments and strongly emphasized by the faunas, the following conclusions based upon a critical study of the Raritan flora may prove of interest to geologists since they clearly indicate that this flora when judged by European standards cannot be considered younger than the Turonian, while a strong case can be made out for its Cenomanian age. Furthermore when judged by American standards it is most decidedly pre-Montana in character.

No attempt is made to make the following brief article polemical in character, and hence arguments which might be drawn from stratigraphy and paleozoölogy are not mentioned, it being the desire of the writer to place a brief statement of the paleobotanical evidence before the public.

The following pages form part of a systematic report on the flora of the Raritan formation in New Jersey prepared over a year ago and to be published by the Geological Survey of that state, and the writer is indebted to the kindness of Dr. Henry B. Kümmel, the state geologist, for permission to publish them in advance of the complete report.

Passing over the somewhat diverse views of the older writers who were inclined to regard the Raritan as of Jurassic age,[1] we find Professor

[1] This age was also claimed for it by the late Professor O. C. Marsh in several papers published a score of years ago.

J. S. Newberry, in 1890, recognizing the Amboy Clays as Cenomanian in age and synchronous with the Dakota Group of the West. Professor Lester F. Ward was the first to point out that the Raritan was older than the Dakota Group, which is undoubtedly the case, and it has been customary in recent years to follow the latter author and regard the former as roughly corresponding to the Gault of England and the Albian of continental Europe. The view here presented is that the Raritan flora is much more closely allied with the Cenomanian of the Old World than it is with the Albian or Gault. At the same time it is quite obviously older than the Magothy flora, that of the Dakota Group, and those of the South Atlantic Coastal Plain,[1] so that if these latter are to be considered of Cenomanian age they are to be regarded as Upper Cenomanian while the Raritan is to be regarded as Lower Cenomanian. European geology furnishes a similar case in the division of the Cenomanian into the substages Rotomagian and Caretonian, although probably the parallelism of substages cannot be carried across the ocean. European paleontology furnishes abundant and well-characterized Cenomanian and Senonian floras for comparison and by this standard the Raritan as well as the somewhat younger Dakota and Magothy floras are clearly Cenomanian floras. The Turonian stage of European geology on the other hand has thus far yielded so meager a flora that it is practically useless as a basis for comparison and it may well be that the flora of the Dakota Group along with its southern and eastern representatives—the Woodbine, Tuscaloosa, Eutaw, Black Creek, Middendorf, and Magothy floras—represents the Turonian stage of Europe. Stratigraphically there is no contrary evidence and the Dakota sandstone would simple go with the overlying Benton which invertebrate paleontologists have long considered as representing the Turonian.

The paleobotanical evidence for the Cenomanian age of the Raritan formation is briefly as follows. On general grounds we find the Raritan flora more complex and modern in its composition than any known Albian flora; for example, dicotyledons make up 68 per cent. of the Raritan flora while not a single dicotyledon is known from the English Gault and the representation of this group of plants in the

[1] Older Cretaceous deposits are known from North Carolina to Alabama, but these are, so far as known, unfossiliferous.

Albian of France and Portugal is very meager indeed and comparable to the display of these plants in the Patapsco formation of Maryland and Virginia, the latter showing a striking parallelism with the Albian of the Old World with at least one identical species and closely allied representatives in several identical genera.

Species which are peculiar to the Raritan formation number 51 as follows:

Acer amboyense Newb.
Aralia patens Holl.
Aralia rotundiloba Newb.
Asplenium raritanensis Berry
Bauhinia gigantea Newb.
Caesalpinia cookiana Holl.
Caesalpinia raritanensis Berry
Calycites diospyriformis Newb.
Calycites parvus Newb.
Carpolithus ovaeformis Newb.
Carpolithus pruniformis Newb.
Carpolithus woodbridgensis Newb.
Celastrophyllum grandifolium Newb.
Celastrophyllum minus Holl.
Celastrophyllum spatulatum Newb.
Chondrites flexuosus Newb.
Chondrophyllum obovatum Newb.
Chondrophyllum reticulatum Newb.
Cornophyllum vetustum Newb.
Dewalquea trifoliata Newb.
Diospyros raritanensis Berry
Eucalyptus parvifolia Newb.
Fontainea grandifolia Newb.
Hedera obliqua Newb.
Ilex elongata Newb.
Ilex amboyensis Berry
Laurophyllum lanceolatum Newb.
Laurophyllum minus Newb.
Leguminosites raritanensis Berry
Liriodendron quercifolium Newb.
Menspermites wardianus Holl.
Myrica acuta Holl.
Myrica cinnamomifolia Newb.
Myrica fenestrata Newb.
Myrica hollicki Ward
Myrica Newberryana Holl.
Myrica raritanensis Holl.
Myrsine oblongata Holl.
Newberryana rigida (N.) Berry
Passiflora antiqua Newb.
Phyllites undulatus Newb.
Planera knowltoniana Holl.
Persoonia spatulata Holl.
Podozamites acuminatus Holl.
Populus orbicularis (Newb.) Berry
Protophyllum obovatum Newb.
Prunus (?) acutifolia Newb.
Rhamnites minor Holl.
Salix pseudo-hayei Berry
Sphaerites raritanensis Berry
Williamsonia smockii Newb.

Obviously these are of little service in correlation; nevertheless all but one or two are dicotyledons of genera which in Europe are found in the Cenomanian, Turonian, and Senonian. Allied forms are largely represented in the Magothy formation, the Dakota Group, and the Atane beds of Greenland.

There are eleven Lower Cretaceous species which persist into the Raritan. These are:

Asplenium dicksonianum Heer
Celastrophyllum brittonianum Hollick
Ficus myricoides Hollick
Frenelopsis hoheneggeri (Ettings.) Schenk
Gleichenia giesekiana Heer
Gleichenia micromera Heer
Gleichenia zippei Heer
Podozamites knowltoni Berry
Podozamites lanceolatus (L. & H.) F. Braun
Sequoia reichenbachi (Gein.) Heer
Thuyites meriani Heer

Of these the ferns and the gymnosperms which make up the bulk of the list are to be regarded primarily as Lower Cretaceous types which survived into the Upper Cretaceous, while the dicotyledons are precursors of the Upper Cretaceous flora. Among the generic types of ancient lineage which are represented in the Raritan are Baiera, primarily a Triassic and Jurassic genus the Raritan species of which is closely related to forms found in the Older Potomac, Williamsonia, a Jurassic and Lower Cretaceous genus, Brachyphyllum, a Triassic and Jurassic genus the Raritan species of which is closely related to, and clearly descended from, *Brachyphyllum crassicaule* Font. of the Patapsco formation, and finally Czekanowskia, a Triassic and Jurassic (chiefly Oölitic) genus.

In no part of the world has a single representative of any of these genera been found as late as the Senonian and it is significant that two of them, Brachyphyllum[1] and Czekanowskia, furnish their last known record in the Cenomanian of Portugal while the last occurrence of Baiera and Williamsonia[2] is in the Cenomanian Atane beds of Greenland.

When the Raritan flora is compared in detail with the Patapsco flora of Maryland and Virginia many common features are brought out which at first sight tend to be obscured by the preponderating dicotyledonous element in the former. In addition to the identical or closely related forms previously mentioned we find among the dicotyledons nine Raritan genera which make their first appearance in the Patapsco. These are Aralia, Sassafras, Celastrophyllum,

[1] The Raritan species *B. macrocarpum* Newb. is recorded from the following American horizons: Montana Group of Wyoming, Dakota Group of Kansas, Magothy formation of Long Island, New Jersey, and Delaware, the Middendorf of South Carolina (?), the Black Creek of North Carolina, the Tuscaloosa and Eutaw of Alabama, and the Patoot beds of Greenland (?), the former of course of Senonian age.

[2] A questionable species is recorded from the Dakota Group and another species occurs in the Magothy formation.

Cissites, Sterculia, Quercus, Populus, Eucalyptus, and Ficus. The genus Celastrophyllum with a large display of forms in both the Patapsco and the Raritan has one identical species, *C. brittonianum* Hollick, while *C. hunteri* of the former is very close and ancestral if not actually identical with *C. angustifolium* Newb. of the latter. Eucalyptus has closely related species at both horizons while Ficus has a common species, *F. myricoides* Hollick, in both formations.

Among the conifers the widespread *Widdringtonites ramosus* (Font.) Berry of the Patapsco is closely related to, if not identical with, the equally common *Widdringtonites reichii* (Ettings.) Heer of the Raritan and succeeding formations. The genus Frenelopsis has closely related species in both while Sequoia and Thuyites have already been mentioned as well as the cycadean genus Podozamites which ranges back to the Triassic. Two Raritan species are recorded from the European Albian. These are *Sequoia reichenbachi* (Gein.) Heer and *Eucalyptus angusta* Velen., the former a very wide-ranging form and the latter recorded from the Albian of Portugal and the Cenomanian of Bohemia.

Turning to the elements in the Raritan flora which ally it with younger floras, we find that six of the Raritan species persist as late as the Senonian of Europe and fifteen are found in the Patoot beds of Greenland which are also usually regarded as of Senonian age. All but four of the latter are, however, found in the Cenomanian beds of that country and practically all of the others and those common to the Senonian of Europe as well occur somewhere in Cenomanian strata. There are thirty-four species common to the Raritan flora and that of the Dakota Group,[1] the former lacking more particularly the numerous forms of Betula, Quercus, Platanus, etc., which characterize the latter. There are 32 species common to the Raritan and to the Atane beds of Greenland, the latter formation being usually regarded as Cenomanian in age, and there are sixty-seven species common to the Raritan and Magothy floras, although these latter figures are somewhat obscured by the difficulty of determining the probable age of many of the species recorded from Long Island and other areas in the vicinity of the terminal moraine and by the additional

[1] This statement applies only to New Jersey forms and is intensified if the supposed Raritan of Staten Island and Long Island is included.

fact that the Upper Raritan at South Amboy, N.J., furnished many of these identical species and it is quite likely that some of the species credited to South Amboy on the authority of Professor Newberry and not since collected may really have come from within the Magothy formation, since the Morgan locality which is of Magothy age would not have been kept distinct from South Amboy as a place-name in Professor Newberry's day.

The known Montana Group flora, the published accounts of which, by Dr. F. H. Knowlton, are contained in *Bulletins 163* and *257* of the U.S. Geological Survey, embraces over one hundred species of which six are common to earlier horizons, two to the flora of the Dakota Group, and five to that of the Raritan, all being pre-Senonian survivors. One of these, *Sequoia reichenbachi*, ranges from the base to the summit of the Cretaceous and hence possesses no significance, and another, *Sequoia heterophylla*, ranges up into the Senonian of Europe. On the other hand not one of the characteristic Senonian (Montana) species occurs in the Raritan and there are twenty-seven Montana genera which are not even represented in the Raritan flora. Not one of the eleven Lower Cretaceous species which persist into the Raritan of the East are found in the Montana flora, although similar Lower Cretaceous floras are known from the Trinity of Texas, the Kootanie of Montana and Canada, the Lakota of the Black Hills, and the Shasta of California. If they survive in the East until Montana time, as has been asserted, why not at some other point on the earth's surface where conditions must have been equally favorable? Furthermore, the characteristic genera of the Raritan flora, such as Aralia, Sassafras, Celastrophyllum, Eucalyptus, Sterculia, Cissites, etc., are entirely unrepresented in the Montana flora, which has a totally different and more modern facies and the genera which are common to the two horizons, such as Myrica, Magnolia, Ficus, etc., have an entirely different set of species.

In conclusion it should be pointed out that the Raritan flora as developed in New Jersey includes over 150 species which are for the most part well preserved and abundantly represented. In striking contrast with this representative flora the supposed Raritan fauna comprises a species of Astarte, one of Ambocardia, one of Rangia (?), two of Corbicula, one of Corbula, one of Turritella, and one of Cym-

bophora, the two latter marine and specifically unidentifiable and the six former brackish in type and of doubtful generic relations.

Dr. Stuart Weller in his admirable investigation of the New Jersey Cretaceous did not actually collect any of these forms and all are based on single occurrences mostly of ancient date made when the importance of definiteness regarding exact localities was not appreciated. None have been subsequently collected, although the number of openings in this area is very great; the region is visited annually by numerous geological students and it is a common practice for the workmen to save unusual objects such as fossils which they find and these usually find their way into the hands of collectors visiting the clay-pits.

The Astarte is listed on the authority of Conrad, the Ambocardia, Rangia, and the two Corbiculas on the authority of Whitfield, and the Turritella and Cymbophora on the evidence of a single slab of sandstone in the State Survey collection obtained over twenty-five years ago and said to have come from Sayreville. It will be obvious that evidence of so scanty and indecisive a character is hardly to be given much weight.

CONCLUSIONS

1. The Raritan flora is clearly shown to be of Upper Cretaceous age.

2. It is shown to be very similar to, but somewhat older than, the flora of the Dakota Group, and to be identical with widely scattered floras usually regarded as of Cenomanian age.

3. It is shown to be totally distinct from the known flora of the Montana Group.

[1] Weller, *Geol. Surv. of N.J., Paleont.*, IV (1907), 28.

THE SECONDARY STRUCTURES OF THE EASTERN PART OF THE BARABOO QUARTZITE RANGE, WISCONSIN

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CONTENTS

INTRODUCTION
Purpose and Scope of the Investigation
SECONDARY STRUCTURES RELATED TO THE FOLDING OF THE RANGE
SECONDARY STRUCTURES NOT RELATED TO THE FOLDING
RÉSUMÉ OF THE SECONDARY STRUCTURES
THE MECHANICS OF THE SECONDARY STRUCTURES OF THE EASTERN PART OF THE BARABOO QUARTZITE RANGE
The Secondary Structures Related to the Folding
The Secondary Structures Unrelated to the Folding
CONCLUSION

INTRODUCTION

Despite the many valuable investigations on secondary structures from theoretical, experimental, and field viewpoints, practically no systematic attempt has been made to correlate secondary structures with stress strain relations which have given rise to major units of structure over large areas. The value of such investigations is being forced home, particularly in areas of poor exposure, where a few scattered details regarding the secondary structures are sometimes the only key to the major structure of industrially important areas.

PURPOSE AND SCOPE OF THE INVESTIGATION

This paper aims to set forth the relation of the joints and other secondary structures of the well-known and well-exposed eastern portion of the Baraboo quartzite range, to the stress strain relations which have developed the structural units of which the district is a whole or a part. On this basis the secondary structures of the district have been classified as those (1) related to the folding of the range, and (2) those not related to the folding of the range.

The[1] Baraboo quartzite district consists of an asymmetrical synclinical fold of pre-Cambrian formations, striking a little north of east and west, with a steep north limb and a gently dipping south limb. (See Fig. 2 of north-and-south section.) The succession from the base up is igneous rock, unconformity, quartzite, slate, iron formation, and dolomite. The only exposures are those of igneous rocks and quartzite, the latter making a prominent ridge encircling the district. The quartzite ridge of the north limb is known as the North Range, while that of the south limb is called the South Range.

Several months were spent in the field during 1905–6 in making several thousand observations on dips and strikes of beds and secondary structures, in an area comprising 5 square miles in the vicinity of Devil's Lake and the Lower Baraboo Narrows. Since then the problem has been reviewed annually by the writer, both in the field and in the office. Both data and results have received the criticism of C. K. Leith, to whom the writer is indebted.

SECONDARY STRUCTURES RELATED TO THE FOLDING OF THE RANGE

The secondary structures in the pre-Cambrian series of the Baraboo quartzite range consist of (1) closed, interrupted joints parallel to the bedding; (2) strike joints which intersect one or more beds and offset between the beds, and constitute a series of overthrust faults of minute throw; (3) strike cleavage both parallel and diagonal to the bedding.

The abundance of the joints related to the folding is dependent upon the inclination of the beds, the distance from the contact of formations, and the strength of the beds. They are more abundant where the strata are highly tilted, than where their dip is nearly horizontal. Thus in the quartzite of the South Range, having a dip of from 5–20 degrees north and striking N. 65–75 degrees east, only about 20 per cent. of the total number of joints are related to the folding; while on the North Range, where the quartzite strikes E.–W. and is vertical or nearly vertical in dip, 40 per cent. or more of the joints are connected with the folding, and of these, the joints

[1] Samuel Weidman, "Baraboo Iron Bearing District," *Wisconsin Geological and Natural History Survey, Bulletin No. 13*, 1904.

parallel to the bedding are the more important. The diagonal strike joints of the North Range are nearly horizontal, owing to the vertical attitude of the beds.

The effect which proximity to a contact has upon the abundance of joints related to the folding is well illustrated on the South Range near Devil's Nose, where the quartzite comes in contact with the granite porphyry to the south. At this place, both bedding and

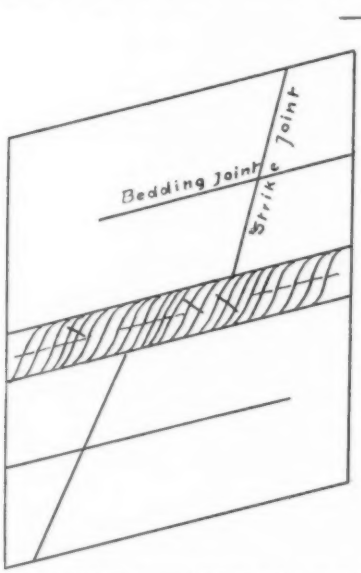

FIG. 1.—Vertical section, normal to the strike on the South Range, showing the relation of the joints connected with the folding in weak, thin beds interstratified with thick, strong beds.

strike joints are so closely spaced as to break the quartzite into a rubble. Away from this contact, the zone of intense fracturing rapidly disappears.

Strong beds have fewer joints related to the folding than weak beds. Throughout the quartzite formation, weak, thin beds of slaty quartzite are intercalated between massive, strong beds of quartzite. Near the site of the old Cliff House on the east bluff at Devil's Lake, there are two such weak beds, each about a half-

foot in thickness, separated by a thick bed of quartzite. Both bedding and diagonal strike joints are present in these beds. The beds strike N. 65 E., and dip 20 degrees north. The diagonal strike fractures are closely spaced *f*-shaped fractures, which are nearly parallel to the bedding plane near the upper and lower surfaces of the bed, while at the center of the bed their dip is 50 degrees north. Some of these *f*-shaped diagonal strike joints are connected with north-dipping diagonal strike joints in the strong quartzite beds. Another set of diagonal strike joints intersects the *f*-shaped set. Fig. 1 shows the relation of the joints connected with the folding in thin, weak beds interstratified with strong, thick beds.

The igneous rocks both on the North and the South Range have joints related to the folding of the range. These joints strike parallel to the strike of the quartzite formation and are vertical or nearly vertical closed joints.

Locally intense dynamic activity accompanying the folding of the range has deformed the formations by flowage, resulting in the development of a schist. On the North Range, at the Lower Baraboo Narrows, in a zone about one hundred feet wide following the contact of the quartzite and the ryolite to the north, the ryolite and some of the quartzite have been rendered schistose. The strike of the cleavage conforms to the strike of the bedding of the quartzite. Its dip is vertical or nearly vertical in the quartzite. In the ryolite it varies from vertical to 65 degrees north.

SECONDARY STRUCTURES NOT RELATED TO THE FOLDING OF THE RANGE

The joints which are most conspicuous in the Baraboo quartzite formation, about 80 per cent. of the joints of the South Range, and approximately 60 per cent. of the joints of the North Range are not related to the folding of the range. Their strike and dip relations differ radically from the joints and secondary structures which are connected with the folding in that their strike and dip relations are independent of the strike and dip relations of the quartzite formation. These independent joints usually occur in sets at right angles to each other. They have considerable continuity both along the strike and the dip, and stand out as gaping, open, vertical, or nearly vertical

fissures. On the South Range, the majority of these independent joints, about 60 per cent. of the total number of joints, strike N. 60 E. and N. 30 W. Nearly 20 per cent. strike N. 20–30 W., and the remainder strike in various other directions of the compass. On the North Range, the principal directions of rupture independent of the fold are N. 30–40 E., and N. 30–40 W., and N.–S.

It has been found that some of the joints unrelated to the folding are connected with deformation of the Cambrian. Thus the predominant directions of jointing in the Cambrian of the eastern end of the quartzite range is N. 60 E. and N. 30 W., which is the predominant direction of rupture of the quartzite on the South Range. This does not preclude the possibility that this set of fissures existed in the quartzite before the deformation of the Cambrian. It has been observed repeatedly that N. 60 E., N. 30 W., N. 10 E., N. 30 E., N. 35 E., N. 50 E., N. 20 W., N. 25 W., N. 35 W., N. 60 W., N. 70 W., N. 80 W. joints are continuous through both Cambrian sandstone and pre-Cambrian quartzite. On the other hand there is abundant evidence that many joints independent of the fold existed in the quartzite before the Cambrian was deposited, since (1) these continuous vertical joints are more prominent in the quartzite than in the Cambrian; (2) the quartzite conglomerate bowlders at the base of the Cambrian are dissected by a diversity of joints, some of them cemented with quartz, many of which could not have been related to the folding, or have developed by processes connected either with the deposition or the deformation of the Cambrian; (3) the Cambrian sandstone has been deposited in wide gaping fissures of the quartzite whose directions are independent of dip and strike relations of the quartzite. Thus at Devil's Lake where the quartzite strikes N. 65–75 E., and dips from 5–25 N., a vertical fissure several feet in width, striking N. 25 W., is filled with Cambrian sandstone.

Among the secondary structures independent of the fold are a few small, vertical shear zones[1] in the quartzite on the east bluff of Devil's Lake. The largest of these strikes N. 85 W. Since the south wall of this fault is more intensely shattered than the north wall, and

[1] See illustration on p. 17, Rollin D. Salisbury, "The Geography of the Region about Devil's Lake and the Dalles of the Wisconsin," *Bulletin No. 5, Wisconsin Geological and Natural History Survey.*

shows a drag toward the south, it is concluded that the south wall has dropped with reference to the north wall. The amount of lateral or vertical displacement is not known, but these movements have very likely been small since the lateral extension of the shear zone appears to be very limited.

RÉSUMÉ OF THE SECONDARY STRUCTURES

The cleavage and a minority of the joints of the pre-Cambrian rocks exposed on the eastern end of the Baraboo quartzite range are related to the folding of the range. On the South Range, about 20 per cent. of the joints, and on the North Range, about 40 per cent. are related to the folding.

Many of the joints of the pre-Cambrian are independent of the folding, having been developed in part before the deposition of the Cambrian, and in part after the deposition of the Cambrian. About 80 per cent. of the joints of the South Range and 60 per cent. of those of the North Range are unrelated to the folding.

THE MECHANICS OF THE SECONDARY STRUCTURES OF THE EASTERN PART OF THE BARABOO QUARTZITE RANGE

It is evident from the description of the secondary structures of the Baraboo quartzite range that there are two distinct types of joints present. The joints of the predominant type, comprising about 80 per cent. of the joints of the South Range, and about 60 per cent. of the joints of the North Range, are independent in their strike, dip, and space relations of the quartzite formation. They were not produced by the folding of the range, but by later deformations. Another type of joints, comprising about 20 per cent. of the joints of the South Range, and 40 per cent. of the joints of the North Range, are connected with the folding of the range. They are the vertical and north-dipping discontinuous, diagonal strike joints, and the bedding joints of the South Range, and the bedding joints and the nearly horizontal strike joints of the North Range. The two types will be given separate attention.

THE SECONDARY STRUCTURES PRODUCED BY THE FOLDING OF THE RANGE

The folding of the quartzite formation was accomplished by slipping between the beds, by fracturing, and by the flowing of the beds.

These movements were in the direction of the anticlinal axis of the fold for an upper bed with reference to a lower bed, and in the direction of the synclinal axis for a lower bed with respect to an upper bed. More deformation took place in weak beds than in strong beds; more in highly tilted beds than in slightly tilted beds. Other factors also influenced the movement. For instance, a large amount of readjustment took place at the contact of the quartzite and the underlying igneous rocks. It may be that this was due to the absence of easy planes of slipping in the massive igneous rocks and that consequently a large part of the required amount of movement took place at the

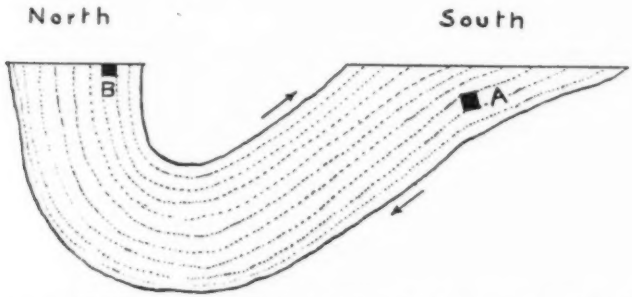

FIG. 2.—Diagrammatic north-to-south section of the quartzite formation. Scale of cross-section: $\frac{3}{4}$ inch = 1 mile. *A* and *B* represent sections of cubes in the beds before deformation.

contact of the two formations. Fig. 2 represents a diagrammatic north-to-south section of the quartzite formation. The arrows indicate the direction of movement in the beds in the process of folding. *A* and *B* represent sections of cubes in the beds before deformation. After deformation, the cubes will be deformed into parallelopipeds, and the sections *A* and *B* will be deformed into parallelograms. Spheres inscribed in the original cubes are deformed into ellipsoids called the strain ellipsoids. Fig. 3 represents *A* of Fig. 2, a vertical section of a cube normal to the strike, and the parallelogram resulting from the deformation of *A*; the circle inscribed in *A*, and the resulting ellipse of strain. Fig. 4 represents a similar section on the North Range where the bedding is vertical. The arrows indicate the direction of slipping between the beds.

The massive quartzite beds and the massive igneous rocks were deformed largely under conditions of fracture, excepting at the contact of the two formations where some of the deformation was accomplished by flow. Those rocks which were deformed under conditions of fracture ruptured as soon as the stresses exceeded the ultimate strength of the rocks. According to the best mechanical analysis, rupture which results from compression takes place along the planes of no distortion or constant area, since these are the planes of maximum tangential stress. In Figs. 3 and 4 they are represented by *XY* and *LM*. It is evident that *LM* is equivalent to the bedding joints,

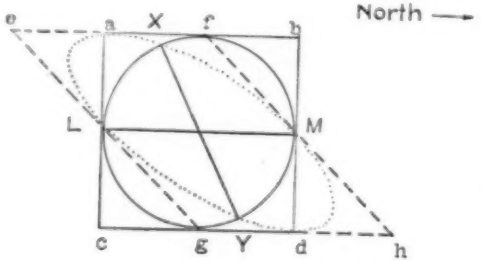

FIG. 3.—*abcd* represents *A* of Fig. 2; *efgh* represents the parallelogram of strain resulting from deformation; the circle inscribed in *A* has been deformed into an ellipse. *XY* and *LM* are the planes of no distortion or the planes of maximum tangential stress, and of rupture.

and *XY* is the vertical, or north-dipping strike fracture, diagonal to the bedding of the South Range, or the nearly horizontal strike fracture of the North Range, where the beds are steeply inclined. The strike fractures constitute a series of overthrust faults of minute throw, which approximately bisect the angle between the longest axis of the strain ellipsoid and a normal to the bed. The initial angle between the longest axis of the strain ellipsoid and a normal to the bed is 45 degrees. The rotation of the longest axis of the strain ellipsoid beyond the initial 45-degree position depends upon the amount of internal flow coincident in direction with the movement between the beds. Since more internal flow takes place in weak beds than in strong beds other conditions being the same, the strain ellipsoids are rotated

more in weak beds than in strong beds, and hence the diagonal strike fractures are more nearly parallel to the bedding in weak beds than in strong beds. This principle accounts for the *f*-shaped fractures in the shaly layers at Devil's Lake, previously described. Near the upper and the lower surfaces of these weak beds, where internal adjustment was greatest, these fractures are more nearly parallel to the bedding than in the center of the beds, where internal adjustment was least. The stretching of the beds parallel to the longest

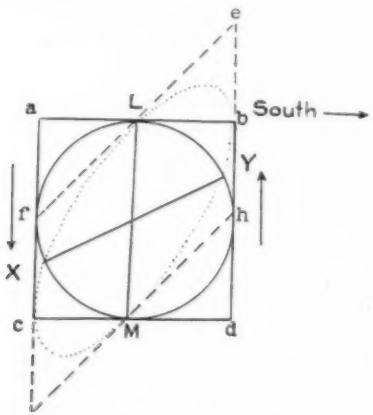

FIG. 4.—*abcd* represents *B* of Fig. 2; *efgh* represents the parallelogram of strain resulting from the deformation of *abcd*. *XY* and *LM* are the intersections of the circle inscribed in *abcd* and the strain ellipse resulting from the deformation of the circle. *XY* and *LM* are the directions of maximum tangential stress, and of rupture.

axis of the strain ellipsoid causes tension fractures to develop normal to the direction of maximum elongation. See diagonal strike fractures which intersect the *f*-shaped strike fractures of Fig. 1.

The development of bedding and diagonal strike shearing joints by the folding on the north limb of the Baraboo syncline is illustrated by Chamberlin and Salisbury in *Geology*, Vol. I, p. 445, Fig. 367. The bed on the left of Fig. 367 is a weak, shaly bed stratigraphically beneath the stronger quartzite bed to the right. In the weak bed the diagonal strike fractures are closely spaced, while both bedding and nearly horizontal, diagonal strike fractures, rather widely spaced,

are visible in the stronger bed. The movement of the stronger bed has been upward with reference to the weaker bed.

The preceding analysis seems to account for all the fractures which show by their strike, dip, and other relations that they are related to the folding of the range. It is to be noted that these fractures are the result of compression rather than tension. Theoretically, it is possible that tension may have caused a set of vertical, gaping strike joints especially on the crest and trough of the fold. It is difficult to determine what part of the strike and dip joints are of this origin, but most of this class have been connected by observation with the compression joints produced by the folding of the range, and thus far no definite evidence of tension joints related to the folding has been found.

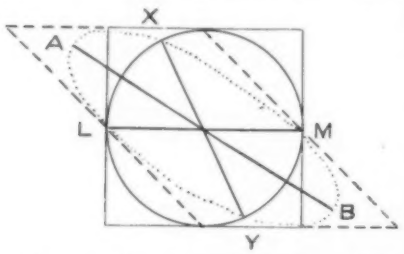

FIG. 5.—*AB*, the longest axis of the strain ellipsoid, is the direction of cleavage in a rock deformed by flow. *XY* and *LM* are the directions of rupture in a rock deformed under conditions of fracture.

Wherever deformation was accomplished largely by flow, cleavage resulted. Cleavage is the capacity of a rock to part along parallel surfaces which are determined by the orientation of the mineral particles parallel to the longer axis of the strain ellipsoid. Fig. 5 shows the strain ellipsoid and the direction of cleavage parallel to the longest axis *AB* of the strain ellipsoid as compared with the directions of maximum tangential stress or rupture *XY* and *LM*. The degree of rotation of the strain ellipsoid, and hence the inclination of the cleavage with respect to the bedding, depends upon the amount of flow. On the North Range, at the contact of the igneous rocks and the quartzite, the plane of cleavage is nearly parallel to the bedding of the quartzite. Farther to the north in the igneous rocks where flowage was less intense, the dip of the cleavage is diagonal to the inclination of the quartzite beds. The cleavage, in the granite porphyry on the South Range at Devil's Nose, is inclined to the north at a steeper angle than the overlying quartzite beds.

THE SECONDARY STRUCTURES INDEPENDENT OF THE FOLD

It is believed that the joints which are independent of the Baraboo syncline are due to tension rather than compression, since they lack strike and dip relations but are usually vertical, open, and occur in approximately rectangular sets whereas, if they were due to compression, they would occur as closed, inclined shearing joints, striking more nearly in one direction.

If the joints, which are independent of the syncline, are due to tension, then the most probable source of tensile stresses would be complex folding under conditions of moderate load. Under such conditions folding will produce rectangular sets of strike and dip joints normal to the direction of tensile stress.

From the description of the secondary structures, it follows that the Baraboo quartzite was subjected to at least one deformation after the folding and before the Cambrian was deposited, and at least one deformation after the deposition of the Cambrian. It seems that one of the principal directions of rupture caused by the deformation following the folding was N. 20–30 W., and therefore it is possible that this was one of the axial directions of this deformation. The directions of maximum rupture in the Cambrian are N. 60 E. and N. 30 W., and therefore assuming that these joints are due to tension caused by complex folding, the axes of the Cambrian fold are approximately N. 60 E., and N. 30 W., in the district. The intermediate systems may have originated with the preceding systems of independent joints, or they may have developed through other stresses.

CONCLUSION

About 20 per cent. of the joints of the South Range, and 40 per cent. of the joints of the North Range are compressive shearing joints developed in planes parallel to the bedding, and in planes parallel to the strike and diagonal to the bedding by strains developed during the formation of the Baraboo syncline. A part of the joints so classed may be due to tension, but there is no direct evidence of this.

The remaining joints, constituting about 80 per cent. of the joints of the South Range, and 60 per cent. of the joints of the North Range, are obviously independent of the folding of the range, having no

relation to the attitude of the bedding. Their origin is uncertain, but a large proportion of them are probably tension joints controlled by larger units of structure than Baraboo Range.

The cleavage locally developed in the rocks of the Baraboo syncline has been correlated with the folding of the range.

The results of this investigation emphasize a principle which has not often received adequate attention, that the secondary structures are parts of larger structures, that these in turn are parts of still larger structures, and that therefore the secondary structures may be the key to the major structure. Description of joints, fractures, cleavage, and faults, as so many isolated details, has value in the interpretation of earth history, only when it leads to the correlation of these structures with the major structures of a district.

DIABASE OF THE COBALT DISTRICT, ONTARIO

REGINALD E. HORE

Here referred to is that portion of the District of Nipissing from Lake Temagami north to the Hudson Bay watershed, an area about eighty miles square. A general description of the region has recently[1] been given by the writer, and some of the geological features are outlined in the following table.

In this area are many recently discovered deposits of native silver, the most important being at Cobalt. All the deposits are in pre-Cambrian rocks, most of the valuable ones in Huronian conglomerate, and a few in Keewatin greenstones and Keweenawan diabase. In all cases the deposits are closely associated with masses of diabase, and are probably genetically connected with them.

In the following description of the diabase, mention is also made of minor intrusions and fissure-fillings, it being suggested that all or part may have originated in the diabase magma and are an expression of the phenomena which occurred on cooling.

The diabase masses.—In almost every township there are outcrops of quartz-diabase. Many of the exposed masses are very irregular in outline, while others show decidedly elongated forms with the longer dimension generally north and south. In several instances the diabase conforms to, and apparently has had its shape determined by, the bedding planes in intruded shales; but some similar masses show in places more stocklike characters, intruding the shales at high angles and forming schistose and slaty contact zones. In rocks other than shales the diabase shows less pronounced sheetlike forms, and appears rather as small stocks and dikes.

General character of the diabase.—The greater part of the diabase masses is of gray to dark-gray color, of medium grain, and with ophitic texture. The specific gravity is about 3.00. The rock is composed chiefly of gray or greenish sodi-calcic feldspar and dull-

[1] R. E. Hore, "Silver Fields of Nipissing," Toronto meeting, Canadian Mining Institute, 1910.

brown pyroxenes. Biotite and black iron oxides are generally visible. Quartz is generally present; but often in small quantity intergrown with feldspar and not always visible to the naked eye. In some specimens there is a decided pink color due to the presence of pink feldspar, and in these portions quartz is more prominent, and grains of pyrite and chalcopyrite are frequently visible. In rarer instances the rock is almost completely made up of feldspar and quartz with but small amounts of ferromagnesian minerals. In some of the masses there are numerous small aplitic veins closely related to the quartz-feldspar portions just mentioned but practically free of ferromagnesian minerals.

Microscopic character.—Specimens of medium-grained gray diabase from all parts of the district show very similar composition. Plagioclase feldspars and pyroxenes are the only minerals present in large quantity. Iron ores are always present in small quantity, and filling the interstices is a micrographic intergrowth of feldspar and quartz.

In thin sections the fresh rock is nearly colorless. Generally the feldspar is somewhat clouded with alteration products, and the pale-brown tinted pyroxene has usually some greenish uralitic or chloritic spots. Angular particles of black ilmenite are generally partially altered to grayish-white leucoxene.

Other minerals sometimes found include biotite, hornblende, quartz, apatite, olivine, chalcopyrite, and pyrite. Among secondary minerals are chlorite, sericite, leucoxene, sphene, limonite, epidote, and carbonates.

Pyroxene.—The common pyroxene is of very pale brownish color. Rarely one finds decided violet-tinted varieties. The shape is irregular and has evidently been determined by the nature of the spaces left after most of the feldspar had crystallized. Less commonly the pyroxene and feldspar crystal boundaries are equally well developed. The size varies greatly in slices from different specimens; commonly they are from 2 to 5 mm. but some of coarser grain show blades of pyroxene from 5 to 20 mm. in length. These large crystals are usually twinned and show marked diallagic striae and they are generally somewhat altered to a greenish fibrous hornblendic substance. Some slides show numerous grains which have the optical

properties of rhombic pyroxenes; but their composition has not been definitely determined.

Feldspar.—The feldspars generally show green or gray tints and occasionally there is present a pink-colored variety. The measurement of angles of extinction by the Michel-Levy method indicates that much of the feldspar is of highly calcic varieties, and chemical analysis of the rock indicates the same. The pink-colored feldspar is more highly sodic, and in aplitic veins showing no ferromagnesian mineral has the composition of albite. The lime-soda feldspars are rarely fresh, partial alterations being indicated by white opaque portions and small grains and flakes of brightly polarizing minerals, the exact nature of which has not been definitely determined. Small grains of epidote are characteristic components of the aggregate. The sodic feldspars, unlike the calcic, are very free from evidences of decomposition.

Ilmenite occurs in typical forms showing the skeleton-like arrangement, and alteration along crystallographic directions to leucoxene. The powdered mineral is not noticeably attracted by the magnet, but large rock masses influence the magnetic needle.

Quartz occurs frequently intergrown micrographically with feldspar, and in the gray diabase is rare otherwise. In the aplitic veins it is often found with the feldspar in typical panidiomorphic structure.

Biotite occurs frequently as dark-brown pleochroic plates, which are conspicuous in the powdered rock, though their weight is comparatively insignificant.

Hornblende.—A green hornblende is a common constituent, especially in specimens which show alterations in the pyroxenes. It is usually in fibrous aggregates and is probably secondary. Some few specimens in which pyroxenes are quite fresh show well-formed green hornblende which is probably primary. A partial analysis of the red rock from James Township (Anal. 4) showed less than 1 per cent total alkalies, and as part at least of this was due to incomplete separation from feldspars, the hornblende in this sodic portion is not an alkali variety.

Olivine is typically absent in the large diabase masses but occurs as yellowish-green grains in varieties containing no micropegmatite. In small intrusives olivine is a common constituent.

Chemical composition of the diabase.—The examination of exposures in all parts of the district proves that most of the diabase is of the medium-grained gray type and the microscopic examination shows that there is great uniformity in the mineral composition of this rock. Chemical analysis of specimens from one locality may therefore be taken as typical of many square miles of the diabase. The following analyses (Nos. 1, 2, and 3) are of specimens taken from the diabase in the silver-producing area at Cobalt. All three specimens were taken a few inches from the surface and in them are evidences of alteration—especially in the feldspars. In reddish portions of the diabase, analysis (see No. 4) shows a higher percentage of silicon and a marked increase in sodium, and microscopic examination of such specimens shows a higher percentage of feldspar-quartz intergrowths and less of pyroxene.

Diabase dikes.—In the diabase there are dikes and veins of various types. The darker-colored dikes are usually very fine grained, distinctly ophitic in texture, high in content of iron oxides, and frequently show olivine. They vary in width from a few inches to several feet. Dikes more than one hundred feet wide are usually very similar in composition to the larger masses. A comparatively small number of the dark-colored dikes show little or no olivine and are characterized by large phenocrysts of white or gray plagioclase among which labradorite has been recognized.

The sodic aplitic veins.—Lighter-colored dikes and veins are in some cases composed almost entirely of sodic feldspars and quartz. Most of the other fillings have quartz or calcite as the chief mineral, and where both are present the quartz is distinctly older than the calcite. These light-colored fissure-fillings are in many cases very irregular in shape, but are generally less than three feet in width. They have various marginal characters. Some are not well marked off from the diabase, grading into it by an interlocking of crystals that leaves no definite contact, thus closely resembling the "contemporaneous veins" of Teall and Geikie. Others show decided lines of demarkation and a few have a soft green aphanitic selvage. In James Township there are numerous such aplitic veins, usually but a few inches in width and commonly gray, flesh-colored, or greenish gray. The former are chiefly composed of feldspar and quartz, while the

	1	2	3	4	5	6	7	8
SiO_2	50.69	50.80	50.48	52.25	73.07	78.28	72.33	58.84
Al_2O_3	16.11	19.42	17.03	17.97	14.88	12.00	12.99	11.24
Fe_2O_3	0.70	0.97	1.25	0.81	0.04	....	none	....
FeO	7.05	6.67	7.81	8.89	2.93	1.19	2.50	0.47
MgO	8.20	5.78	9.32	6.46	1.30	0.37	0.97	0.35
CaO	12.09	12.68	10.96	7.27	0.66	0.29	1.73	12.17
Na_2O	1.78	1.60	1.95	3.61	6.17	6.89	7.60	6.91
K_2O	0.78	0.37	0.24	1.71	0.46	none	none	none
H_2O+	1.65	0.86	0.82	1.80	0.90	0.61	1.09	0.40
H_2O-	0.16	0.25	0.22	0.04				
CO_2	....	....	....	....	....	none	1.00	9.84
TiO_2	0.53	0.43	p.n.d.	p.n.d.	0.41	0.34	0.74	0.26
CoO NiO	0.11	0.01	0.04	....	none	....	....	....
S	0.07	....	....	....	....	....	....	..13
Sum	99.82	99.84	100.12	100.81	100.82	99.97	100.95	100.61
Rock name	Quartz-diabase	Quartz-diabase	Quartz-diabase	Quartz-diorite	Aplitic soda granite	Aplitic soda granite	Aplitic soda granite	Aplitic soda granite
Locality	Silver Bar Mine, Cobalt, Ont.	Kerr Lake Mine, Cobalt, Ont.	University Mine, Cobalt, Ont.	James Twp., Nipissing, Ont.	University Mine, Cobalt, Ont.	James Twp., Nipissing, Ont.	University Mine, Cobalt, Ont.	James Twp., Nipissing, Ont.
Analyst	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore	N. L. Bowen	N. L. Bowen	N. L. Bowen

greenish ones contain a fibrous chlorite. Frequently the aplites have a considerable percentage of finely crystalline calcite, and small crystals of titantite and grains of epidote are common. The quartz and feldspar are usually in equidimensional grains as typical in aplites, while occasionally there are micrographic intergrowths, and in some specimens rounded grains of feldspar in a matrix of later-formed quartz. Analysis by N. L. Bowen of a specimen from one of these veins is given in the table on p. 275 (anal. No. 6).[1]

On the property of the University Mine in Coleman Township is a larger fissure-filling, exposed at intervals for eight hundred feet, and in places over fifty feet wide. Analyses of specimens of this vein are given in Columns 7 and 8. The specimen No. 7 is a fine-grained gray soda granite taken from the wide part of the vein. The specimen No. 8 was taken about three hundred feet from No. 7, and is finer in grain and free from carbonates. Portions of the rock contain a high percentage of calcite, which fills interstices between the earlier-formed feldspar and quartz.

Quartz and calcite veins.—The most common type of minor fissure-fillings is composed of white quartz. Chlorite and fibrous amphibole are common constituents and pyrite, chalcopyrite, and galena are frequently present. In some of the quartz veins there is considerable calcite filling interstices between well-formed quartz crystals.

Relation of the diabase and sodic aplitic veins.—In some large sills there are portions, one to two hundred feet from the bottom, which are pink, coarse grained, and more highly sodic than the gray, medium-grained, main mass, into which they pass by insensible gradations. Similar pink-colored rocks occur as irregular-shaped masses distinctly marked off from the gray diabase. The microscopic examination shows that the pink-textured portions have a higher percentage of those minerals which were last to crystallize in the gray diabase. The aplitic veins are composed almost entirely of the chief of these last-formed minerals—sodic feldspar and quartz.

There is a lack of evidence which would indicate any extensive fusion and absorption of the intruded rocks. Xenoliths are not

[1] N. L. Bowen, *Canadian Mining Journal*, April 15, 1909; see also *Bulletin of Canadian Mining Institute*, December, 1909.

found. The pink rock has not a composition intermediate between the gray diabase and the intruded shales. It seems probable therefore that the variations in composition are the natural consequence of the cooling of a molten magma whose composition was near that of the gray diabase, except that the latter does not contain the same proportion of volatile constituents.

The aplitic veins seem to have been formed by the last secretions from the diabase magma, filling fissures which developed after most of the mass had solidified, while the pink-colored diabase and gabbro masses represent the solidification from the molten magma at an intermediate stage in a process of differentiation.

The irregular pink-colored patches and streaks were probably intruded earlier into hot but viscous portions of the cooling masses. In these cases it appears that there has been differentiation in the diabase magma but not *in situ*. Some other pink portions of the thick sills are probably the result of differentiation *in situ*.

ROCKS OF THE NIPISSING SILVER FIELDS

CENOZOIC	*Recent:*	Clay, marl, peat.
	Pleistocene	(1) Coarse unstratified material—sand, gravel, and bowlders; (2) Stratified clay with some sand.
	Great unconformity	
PALEOZOIC	*Silurian:*	Grey limestone with some interbedded greenish shales, and at the base an arenaceous conglomerate. Correlated with Niagara of New York state.
	Great unconformity	
ALGONKIAN	*Keweenawan:*	Igneous intrusives only. Chiefly quartz diabase and quartz gabbros with acid differentiation products. Some olivine diabase and diabase porphyrite dykes.
	Igneous contact	
	Huronian:	Sedimentary rocks only.
		(1) An upper series. Probably equivalent to Middle Huronian of Lake Superior. Chiefly feldspathic quartzite with some conglomerate.
	Slight unconformity	
		(2) A lower series. Probably equivalent to Lower Huronian of Lake Superior. Chiefly greywacke, shale, conglomerate, and feldspathic quartzite. The conglomerate pebbles are mostly of holocrystalline igneous rocks, the matrix greywacke and grey shale.

The rocks are seldom schistose except as the result of contact metamorphism.

Great unconformity

ARCHEAN *Laurentian:* Igneous intrusives only. Holocrystalline light-colored siliceous rocks. Chiefly granites, diorite, syenites, and gneisses.

Igneous contact

Keewatin: Igneous and sedimentary rocks. All are much metamorphosed, and many schistose.

The relative age of the igneous and sedimentary rocks is doubtful; but the iron formation is probably younger than much of the igneous portion. The agglomerates were probably contemporaneous with some of the non-clastic volcanic rocks, and may be contemporaneous with the other sediments. The igneous rocks are chiefly of *extrusive* types.

Extrusives: (1) Dark-colored basic rocks—basalts—mostly with composition and texture of altered diabases.

(2) Light-colored siliceous rocks—felsites and felsite porphyries—mostly quartz porphyries which have been altered to sericite schists.

Intrusives: (1) Basic rocks, mostly diabase and gabbro.

(2) Siliceous rocks, mostly quartz porphyries and porphyrites.

Sediments: (1) The iron formation—chert, jasplite, carbonates, slates, and green schists.

(2) Fragmental volcanic rocks—a grey felsite agglomerate.

THE COLLECTING AREA OF THE WATERS OF THE HOT SPRINGS, HOT SPRINGS, ARKANSAS[1]

A. H. PURDUE
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Introduction.—The unusual interest with which the hot springs of Arkansas are regarded because of their temperature and their renown for medicinal purposes, furnishes the reason for the somewhat exhaustive consideration of the source of their waters, which follows. The conclusions herein presented were reached in the course of field work on the structure and stratigraphy of the area about Hot Springs, during the summer of 1909. The paper is written with the assumption that the waters of the hot springs are meteoric. This assumption is made partly because geologists in general have come to think of most of the ground-water as having such origin, and partly because the recent studies of Mr. Walter Harvey Weed upon the waters of these springs indicate that they are meteoric.[2]

General topographic relations of the hot springs.—In casting about for all possible sources of the waters of the hot springs, the highlands of Arkansas and Oklahoma and those of the Appalachian province command attention.

The highlands of Arkansas and the eastern part of Oklahoma are divided into a northern and a southern part, separated by the valley of the Arkansas River. The northern division consists of the Boston Mountains, which are a dissected plateau, reaching the height of somewhat more than 2,200 feet above sea-level, and a much lower area to the north of them. The southern division consists of the Ouachita Mountains, which cover an area about 50 miles wide and 200 miles long. These mountains consist of ridges, the direction of which is in the main east and west and some of which surpass 2,000 feet in height.

[1] By permission of the Chief Geologist, U.S. Geological Survey.

[2] "The Hot Springs of Arkansas," *Senate Doc. No. 282*, p. 90, Washington, D.C., 1902. Prepared under the supervision of the Secretary of the Interior.

In the Appalachian province, the Cumberland Plateau exceeds 2,000 feet and the Appalachian Mountains 6,000 feet in height.

Topography of the area about the hot springs.—The topography in the vicinity of the hot springs is shown by the accompanying relief map (Fig. 1). The springs, indicated by the cross, emerge from the western end of Hot Springs Mountain, which is known as Indian

FIG. 1.—Relief map of the Hot Springs area

Mountain east of West Branch of Gulpha Creek. Immediately north of Hot Springs Mountain is North Mountain, which continues west of Hot Springs Creek, as West Mountain. Three miles west of the springs, West Mountain swings around in a horseshoe curve and extends northeastward, and is known as Sugarloaf Mountain. Hot Springs Creek, a considerable stream, flowing southward, carries off the overflow from the hot springs and the drainage of a portion of the valley just south of Sugarloaf Mountain.

This valley is from a mile to a mile and a quarter in width. About two miles northeast of the hot springs where West Branch of Gulpha Creek cuts through North Mountain, there is a limited area with an elevation of 620 feet. The greater part of the surface, however, stands above the 700-foot contour, and the highest hills exceed 800 feet. The highest elevation at which any of the springs emerge is 640 feet.

Structure and rocks of the highland areas.—The general structure of the highland area is that of a broad syncline with its trough in the Arkansas Valley. The rocks are sandstone, limestone, and shale. Those of the Boston Mountains and the area to their north lie for the most part horizontal, but in the south half of the Boston Mountains they dip perceptibly to the south, and in the Arkansas Valley pass under several thousand feet of younger rocks.

The general structure of the Ouachita area is that of an anticlinorium dipping southward under the Mesozoic and Tertiary rocks and northward beneath those of the Arkansas Valley. The rocks are intensely folded, to which, with erosion, is due the narrow valleys and parallel ridges of the area. The folds in the main have an east-west direction, but at Hot Springs and for some distance to the west, their direction is northeast-southwest. The individual folds are not continuous for great distances, but are short and overlap each other laterally. Thrust faults, approximately parallel to the strike, and of many hundred feet displacement, occur in the Ouachita Mountains and the Arkansas Valley. The hot springs are located in the eastern part of the Ouachita area.

The stratified rocks of the Appalachian province are sandstone, limestone, and shale. Their continuity is broken by faulting, and the rocks of the Cumberland Plateau dip away from the Cincinnati arch toward the southeast. The rocks west of the Cincinnati arch are practically horizontal, and are truncated along the Embayment border. Against their truncated edges, the later rocks of the Embayment area rest unconformably.

Structure and rocks of the area about the hot springs.—Like the remainder of the Ouachita region, the area about the hot springs is intensely folded. The folds are closely compressed and all are overturned to the south. As a result, the dips are to the north. Some

of these are as low as 15 degrees and they seldom exceed 60 degrees. This means that, at the points of greatest overturning, the rock layers lie literally upside down, and, in folding, have described an arc of 165 degrees.

The surface rocks about the hot springs are shown in the following section:[1]

		Feet
Carboniferous	Stanley shale	3,500
	Hot Springs sandstone	100
Age unknown	Arkansas novaculite	380
	Missouri Mountain slate	50
Ordovician	Polk Creek shale	210
	Bigfork chert	570

The Bigfork chert is in layers from two to twelve inches thick. Throughout most of the formation, it consists almost entirely of chert, but in parts the layers are separated by thin beds of shale, and in other parts shale is the main constituent. The chert is very brittle and is intensely fractured from the folding it has suffered.

The Polk Creek shale overlies the Bigfork chert, and is a very black, somewhat siliceous shale, though soft enough from its graphitic nature to soil the fingers in handling. The upper part contains a few thin, siliceous beds, but the lower part is wholly shale.

The Missouri Mountain slate, as it occurs in the vicinity of the hot springs, is a red to brown or yellow shale, depending upon the stage of weathering. Further west in the Ouachita area, it is a true slate.

The Arkansas novaculite, as it is exposed in the vicinity of the hot springs, consists of three parts: A lower, massive one 275 feet thick, made up of heavy beds of much fractured novaculite. It is from this part of the formation that the Arkansas abrasives are secured. This is followed by fifty-five feet of very black clay shale, weathering in places to light gray; and this by fifty feet of what appears to be rotten, porous novaculite. The section of the novaculite formation over the Ouachita area varies greatly with the locality.

The Hot Springs sandstone[2] is a gray, quartzitic sandstone, in

[1] With the exception of the Stanley shale and the Hot Springs sandstone, these names were first applied to the formations as they appear in Montgomery County, Arkansas.

[2] This name has not been used before in Arkansas.

beds from three to eight feet thick. The basal ten feet is conglomeratic. It is from this formation that most of the hot springs issue, which fact, however, is not significant.

The Stanley shale is composed mainly of black to green clay shale, though a large percentage of it consists of rather soft, greenish sandstone. This shale skirts Hot Springs and West Mountains. While a large part of the city of Hot Springs stands on this formation, only the waters of those springs that issue at the lowest levels move through it.

Possibilities of ground-water flowage.—While the altitude of the Boston Mountains is sufficient to give the ground-water enough head for it to emerge at the height and distance of the hot springs, the intervening structure makes such impossible. The closely compressed folds, their lateral overlapping, and the faulting of the Ouachita area

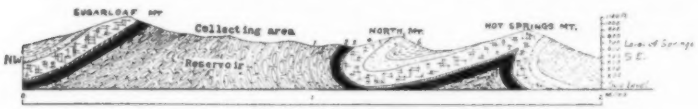

FIG. 2.—Northwest-southeast section at Hot Springs. 1. Bigfork chert. 2. Polk Creek shale. 3. Missouri Mountain slate. 4. Arkansas novaculite. 5. Hot Springs sandstone. 6. Stanley shale.

to the north and west of the hot springs are such as to prevent the uninterrupted movement of ground-water except for short distances. Likewise the stratigraphy, structure, and topography to their south eliminate that area as a possible source of the water; and the structure of the Appalachian province and the Embayment area is such as to preclude the former as a possible location of the water head.

The collecting area.—It follows from the above that the collecting area must be in the near vicinity of the springs, and a study of the topography, stratigraphy, and structure thereabout locates it with reasonable certainty. A glance at the section (Fig. 2) from Sugarloaf Mountain southeastward through Hot Springs Mountain will indicate the collecting area. The surface of the overturned, anticlinal valley between Sugarloaf and North mountains is higher than the level of emergence of the springs. The rocks outcropping over the area are the Bigfork chert and the Polk Creek shale, the former occupying most of the area.

The considerable thickness of the Bigfork chert, its much fractured nature, and the thin layers of which it is composed, all combine to make it a water-bearing formation of unusual importance. The greater number of the fine springs in the Ouachita area between Hot Springs and the western border of the state come from this horizon. In many places this formation occurs in anticlinal valleys with its highly inclined beds truncated, affording the most favorable condition for the intake of water. A glance at Fig. 2 will show that these conditions obtain in the area between North Mountain and Sugarloaf Mountain. In addition to the favorable structure for the reception of water, there is the stratigraphic condition for its retention brought about by the overlying Polk Creek shale. As a consequence of the topography, structure, and stratigraphy, the water is collected in the basin shown in the map (Fig. 1), conducted through the Bigfork chert

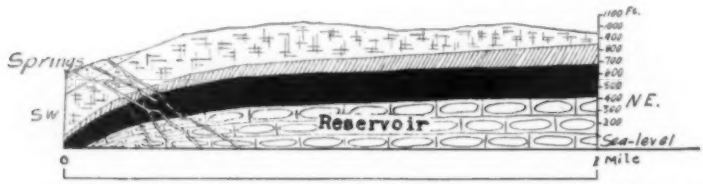

FIG. 3.—Northeast-southwest (longitudinal) section of Hot Springs Mountain, showing the hypothetical water conduits at the plunging end of the anticline. Symbols, same as in Fig. 2.

beneath the North Mountain syncline, and forced up into the Hot Springs anticline, at the western end of which it emerges in the hot springs. Including several of weak flow, there are said to be seventy-two of these springs, and they are confined to a narrow strip about a quarter of a mile long.

The exact location of the springs is attributable to the southwestern plunge of the Hot Springs anticline, and as has been stated by Mr. Walter Harvey Weed[1] probably to fracturing and possibly slight faulting in the process of folding, as shown in Fig. 3.

While not relevant to the title of this paper, it might be added that the considerable number of dikes in the vicinity of the hot springs, the large number (eighty are known) only four miles to the southeast,

[1] *Loc. cit.*

on and near the Ouachita River, and the areas of igneous rock at Potash Sulphur Spring, Magnet Cove, and other near places, force the suggestion upon one that the waters of the springs owe their temperature to passing over hot rocks, or the vapor from such, in some part of their underground course. The fact that these are practically[1] the only hot springs within the Ouachita area, though there are scores of cold springs issuing from the same formations and under the same geologic relations, gives this suggestion great weight; but inasmuch as some of the hot springs are said to be unusually radio-active, there is the alternative suggestion that atomic decomposition in igneous rocks (which may have lost their magmatic heat) is the source of the high temperature of the water.

[1] Recently a spring, said to have a temperature of 98° to 100° F., has been discovered issuing from the Arkansas novaculite in the bed of the Caddo River at Caddo Gap, Montgomery County.

Reviews

Preliminary Report on a Part of the Similkameen District, British Columbia. By CHARLES CAMSELL. Geological Survey of Canada.

This report covers the region about Princeton, including the Roche River, Copper Mountain, Kennedy Mountain, and Bear Creek Mining Camps, and the Tertiary coal basin of Princeton. Copper ores occur in lodes with some gold and silver. Exploration of these deposits has been considerable, but the development is limited. Placer mining has been carried on in the district since 1860, but is of little importance now. Platinum is found in the placers with the gold. E. R. L.

Report on a Portion of Conrad and Whitehorse Mining Districts, Yukon. By D. D. CAIRNES. Canada Department of Mines. Geological Survey Branch.

The district lies along the western edge or the Central Yukon Plateau region just east of the Coast Range. The ores are chiefly of gold, occurring in quartz veins, sometimes with rich values in silver. The work on these veins was begun in 1905, and has since developed rapidly. Several seams of anthracite coal outcrop in the district, and should be of considerable value in the near future. E. R. L.

Geology of the Taylorsville Region, California. By J. S. DILLER. U.S. Geological Survey Bulletin 353.

The topographic elements of the northern Sierras, to which the Taylorsville region belongs, are three fault blocks with prominent escarpments to the east and long gentle slopes to valleys along the western borders. Sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age, and igneous rocks belonging to several periods are found in the region. The most important periods of igneous activity are connected with the compression and deformation of the rocks of the Sierra Nevada at the close of Jurassic, and with the great uplifting and faulting at the close of the Cretaceous. No great mines have been developed, but forty or fifty smaller ones have yielded a total value of $7,000,000, almost wholly in gold, with a little silver and copper. E. R. L.

The Lime and Cement Resources of Missouri. By H. A. BUEHLER. Missouri Bureau of Geology and Mines. Vol. VI, 2d series.

In this report the materials suitable for use, the properties and methods of manufacture of lime, and the various kinds of cement are described in considerable detail, the resources and development being described for each county separately. The available deposits of limestone, clay, and shale are extensive, and the industry is a very important one.

E. R. L.

Preliminary Report on a Portion of the Main Coast of British Columbia and Adjacent Islands in the New Westminster and Nanaimo Districts. By O. E. LEROY. Canada Department of Mines. Goelogical Survey Branch.

The area described embraces that portion of the coast of British Columbia between the international boundary line and the mouth of Powell River on Malaspina Strait, and lies almost wholly in the mining district of New Westminster.

The rocks in the district include sedimentary rocks of Devonian, Carboniferous, Cretaceous, and Quaternary (Glacial) age, and Paleozoic, Mesozoic, and Eocene igneous rocks. The principal ore deposits, which lie chiefly in Paleozoic rocks, are of copper and iron. The magnetite deposits are extensive, but have not been developed. A short summary of the copper deposits would add to the value of the report.

E. R. L.

The Laurentian System in Eastern Canada. By F. DAWSON ADAMS. *Quarterly Journal of Geological Society*, Vol. LXIV, 1908, pp. 127–48, and pls. XI–XIII.

This paper is an outline of the chief results obtained from an extended study of a selected area, the object being to determine the character, structure, relations, and origin of Logan's Laurentian succession in eastern Canada.

In Logan's original classification, the Laurentian included two series, the Grenville series, and the Lower Orthoclase (Fundamental) Gneiss. The former is shown to be, in origin, a great development of Proterozoic sediments; the latter consists of great bodies of igneous rock underlying and intruded into the sediments. The term Laurentian is restricted to the underlying series. The Grenville series presents by far the greatest thickness of pre-Cambrian limestone in North America.

E. R. L.

The California Earthquake of April 18, 1906. By the State Earthquake Investigation Committee, A. C. LAWSON, Chairman. Washington: Carnegie Institution, 1909. Two vols. with Atlas. Vol. I, pp. xviii+451 (4to); pls. 146. With folio atlas of 25 maps and 15 sheets of seismograms.

The long delay in the appearance of the second volume of this report makes it advisable to call attention to the great importance of the part already published. Even without the second volume, this monograph is one of the most elaborate of any earthquake report that has yet appeared. The only reports inviting comparison upon this basis are those by the Naples Academy of Science on the great Calabrian earthquake of 1783 (xiv+351 folio pages with atlas and 69 plates); by Robert Mallet on the so-called Neapolitan earthquake of 1857 (830 pp.); by the French Academy of Science upon the Andalusian earthquake of 1884 (772 pp. and 42 pls.); and by R. D. Oldham upon the great Assam earthquake of 1897 (xviii+379 pp. with 42 pls. and 3 maps).

The already published text upon the California earthquake is in very large part an edited collection of extremely valuable data gathered by a large number of geologists, the work of correlation and presentation having been carried out by a geologist who has made important contributions to American geology. To the geologist, the seismologist, the engineer and builder, and to the general reader, the report is one of very great value, but its sphere of usefulness must be very much limited by the difficulty of procuring it (the already published portion is sold for $17.50); and to some extent also by the form of publication, since the atlas intimately illustrates the text but is so unwieldy that it cannot be kept near it in any standard library. The lack of any index whatever must also be greatly regretted, since it is only by running through the table of contents that any desired subject can be located. To illustrate, one of the most valuable sections of the work describes experiments along new lines made with a shaking machine by Mr. F. J. Rogers. It is necessary to read four pages of contents in order to find the page reference, and even then the author's name does not appear.

As regards the atlas, the folio size has apparently been fixed to allow of the introduction of fifteen 30″ quadrangles of the map of the United States, upon which by means of a single uninterrupted red line the general course of the earthquake rift is indicated. In view of the lack of all detail, it would seem that the relation of the rift to the topographic relief could be much better brought out upon a single map of correspondingly reduced scale. Throughout the report the attempt has clearly been to set down the

observations made, unmodified by special views of origin; and such a report must always remain of the greatest value, however much theories should change. A few pages only are devoted to discussion of results, and theories of cause are either briefly set forth or implied rather than explicitly stated. By many this will be regarded as unfortunate, since they will wish to know the lines of evidence by which the conclusions were reached. It appears with sufficient clearness that in the view of the chairman of the commission, the disturbance of April 18, 1906, was due entirely to a differential mass movement of the ground upon a single surface (or narrow zone) of fracture—the so-called St. Andreas Rift; and that all earlier historic earthquakes within the same province, with the exception of that of 1868, were likewise caused by movements upon this same rift. The earthquake of 1868 is ascribed to a similar adjustment upon the degraded fault along the northeast margin of the Santa Clara Valley and San Francisco Bay. Other possible displacements, within the same province at the same times, have in the report been excluded from consideration, perhaps because none were revealed through surface breaks.

It has further been assumed that the local energy of the disturbance was determined solely by distance from the rift, the apparent surface intensity, when not in harmony with this law, being accounted for solely by differences of elasticity within the sub-surface materials. This is certainly of very great interest, provided it is true; but the maps and printed observations do not make it by any means conclusive. Map No. 23 of the atlas (distribution of apparent intensity) does not make it appear even probable. Dr. G. K. Gilbert, a member of the commission, some four months after the earthquake, published a short paper in which he advanced the same theory, though he significantly added:

> But after making due allowance for differences in natural foundation and for differences in the resisting power of buildings, there remain various anomalies for which satisfactory explanation has not as yet been found. The natural foundation of Oakland is similar to that of San José, and its distance from the earthquake origin is about the same, but the injury to its buildings was decidedly less; and *Santa Rosa, standing on ground apparently firmer than that at Oakland or San José and having a somewhat greater distance from the fault, was nevertheless shaken with extreme violence.*[1]

It is too early to discuss these anomalies. With the data now in hand it seems to be true that there are outlying tracts of high intensity surrounded by areas of relatively low intensity; and these features, if they shall be fully established, will doubtless affect in some important way the general theory of the earthquake.

[1] The italics are mine.—W. H. H.

It is the discussion of such difficult but crucial points that the reader seeks in vain in the final report. Passing in review the whole history of great earthquakes, it would seem remarkable, indeed, if the cause of one were not the cause of most, if not all, such movements of the crust. A criticism of the report, which has been made by several reviewers, is that it has ignored earlier work; and, excepting only the Mallet conception of isoseismals, it seems that the report might have been written in its present form if no report upon any earthquake had ever been published.

Repetition of a recent triangulation by the U.S. Coast and Geodetic Survey was made subsequent to the earthquake and revealed important changes in the location of monuments. The report upon this resurvey by Messrs. Hayford and Baldwin is of very great interest, since a comprehensive retriangulation after a destructive earthquake has been made before in but a single instance—that of the great Assam earthquake of 1897. No attempt can be made in the compass of this review even to mention the many important subjects which are treated in the report.

W. H. H.

University Geological Survey of Kansas. Vol. IX. Oil and Gas Report, 1908 [1909]. Pp. 600; pls. and maps, 110.

The Upper Carboniferous of Kansas, because of the abundant and beautifully preserved fossils which it furnishes; because of the thickness of its exposed section and the regularly alternating structure of limestones with shaly or sandy beds, and because of the distinguished and historic names which are associated with the literature that has grown up about it, has become in some measure a standard or reference section for invertebrate paleontologists when dealing with the Upper Carboniferous of the United States. Real additions to our knowledge of this series, therefore, will be of interest to all geologists and especially to those who are engaged in stratigraphic paleontology. The latest volume of the University Geological Survey of Kansas, however, contains matter for all tastes. It is divided into eleven chapters, each of which constitutes a more or less distinct paper dealing with the wide range of subjects which the geology of Kansas naturally presents. The first chapter comprises a geological and historical account of the discovery of oil and gas (pp. 5–41). It was written by Erasmus Haworth. The second and third chapters are jointly by Erasmus Haworth and John Bennett, and give the history of field work in Kansas (pp. 42–56) and a discussion of the general stratigraphy (pp. 57–160). The three succeeding chapters are by Erasmus Haworth and are entitled, respectively, "Detailed Geology of Oil and Gas" (pp. 161–79), "Life

of Oil Wells and Gas Wells—Gas Pressure" (pp. 180–98), and "Chemical Conditions of Oil and Gas" (pp. 199–227). The second of these three chapters also includes an abstract of a paper by Dr. C. Engler on the "Origin of Petroleum" (pp. 198*a*–198*d*). Chap. vii, comprising pp. 228–302, was written by H. P. Cady and D. F. McFarland and deals with the chemical composition of gas, as the following chapter by F. W. Bushong deals with the chemical composition of petroleum (pp. 303–17). The title of the ninth chapter is "Coal-Measure Faunal Studies," by J. W. Beede and A. F. Rogers, and it comprises pp. 318–85. The last two articles were written by E. H. Sellards, who deals with "Fossil Plants of the Kansas Upper Paleozoic" (pp. 386–500), and "Fossil Cockroaches in the Kansas Coal Measures and Kansas Permian" (pp. 501–41).

The one of these papers which the writer's studies permit him to discuss most intelligently is that by Beede and Rogers on the Faunal divisions of the Kansas Coal Measures. This is a subject well worthy of investigation for if correlations are to be made with the Kansas section, it will probably be more with groups than with individual formations, some of which are only a few feet in thickness. Previous groupings of the formations had been suggested by authors, partly on considerations of stratigraphy, partly, as in Prosser's stages proposed for divisions in the upper portion of the section, on paleontologic evidence, but nothing which was as comprehensive and consistent involving the formations of the entire series and based on such an accumulation of data. In this connection it seems unfortunate that the classification and nomenclature of Beede and Rogers, resting it would appear especially on paleontological evidence, does not agree with that of Haworth and Bennett in the same volume, which appears to have sprung from considerations of lithology, topography, etc. Although I have myself studied the Kansas faunal sequence in a somewhat incidental and dilettante manner, I am not prepared with any criticism of the validity of the groups proposed. These will stand or fall as they meet the test of experience, but the authors certainly know the Kansas section better than any other paleontologists and there is no reason to doubt that their classification is, taken all in all, the best that has been proposed.

It seems rather doubtful, however, after reading their paper, whether the Kansas section can be used as a reference section with any degree of advantage. The authors find such variations in the faunas collected at different points in certain of the formations that were it not for their stratigraphic connection they would hardly be believed to be the same horizon. In my own work on the Kansas faunas similar anomalies were observed which led me to suspect the correctness with which the beds had been traced.

The generalization of the formational fauna by means of collections taken at numerous and widely separated stations does much to eliminate the false premise otherwise involved and doubtless the limit of error is still farther reduced by considering not the faunas of individual formations but of groups of formations. For this reason a grouping of the Kansas beds was especially desirable.

Some of the faunal modifications are regarded by the authors as the result of conditions of sedimentation, while others are ascribed to barriers, location and character not specified. Diversity of fauna at different points in the same bed of limestone can clearly not be ascribed to the interference of barriers nor probably can the fact that the shales with which the limestones alternate are usually almost barren of fossil shells, or at times contain invertebrate faunas of appreciably different facies from the adjacent beds of calcareous nature. Since now we have faunal variations, some of which can clearly be assigned to environmental causes, the propriety seems doubtful of explaining others by hypothetizing a different cause.

The classification proposed by Messrs. Beede and Rogers may be summarized as follows: The forty-six formations from the Cherokee shales below, to, and including the Neosho formation, to which limits the authors confine the Pennsylvanian, are divided into ten stages containing from one to nine formations each, and the stages are again grouped into four series, each of which contains two or three stages. The basis for this classification is presented in the form of two charts, one of which is of such novel construction that it requires the second as a key to it.

This table seems especially designed to show the abundance of species in the different formations, a fact to which the authors attach much importance, because they connect it with the ability to migrate. They say, "Another point of some significance which may be determined by the chart is the time at which migration of individual species is most apt to occur. It is well understood that the most vigorous species, represented by large numbers of individuals, are the ones that migrate most readily, other things being equal, and form the cosmopolitan elements of the various periods" (p. 327). And also below on the same page: "Other things being equal, it is believed that a species is more apt to withstand the vicissitudes of migration at this time [its culmination] than at any other on account of its greater numbers and reproductive ability and greater vitality." Now some of the fundamental facts in these statements seem doubtful to me. Are the species represented by large numbers necessarily the most vigorous? Are the most vigorous species the ones that migrate most readily, other things being equal? And are other things ever equal? As to the time of migra-

tion of any one species the case stands perhaps a little better. But even so, the migration of species is governed by so many factors extrinsic as well as intrinsic that inferences drawn from the fact of abundance can hardly lead to any trustworthy conclusions.

In short, it seems to me that the authors attach too much and possibly not altogether the correct significance to the fact of abundance. At all events, the matter is not so lightly to be disposed of.

Regarding their identification, the authors say that they have used conservatism: "Usually, where there is a question concerning the advisability of splitting up an older idea of a species, the old idea is followed here." As the paper is not accompanied by descriptions or figures, it is impossible for the reader to ascertain what breadth of specific limitation is assumed in any case. For my own part, it has always seemed to me that the relations between faunas are best shown when the discrimination of species is made with the keenest criticism, tempered with good judgment. It is to be hoped that in their final account of the fauna which the authors lead us to expect a refined discrimination of species will be employed.

The authors note some departures from the taxonomic nomenclature employed in previous papers which the present one in a way seems to summarize and be the fruit of, but the changes are hardly enough to bring the paper abreast of the time in this particular. These changes are, however, purely nomenclatural and do not necessarily affect the accuracy of the conclusions arrived at. They can the more be pardoned because the volume has been a long time in press and doubtless some of them came to the authors' attention after the report had left their hands.

The paper abounds in typographical errors, chiefly in connection with scientific names, and in other errors for which the printer cannot be blamed. One of the most serious, at least in the estimation of a paleontologist, is that the imprint is for the year 1908, while, as is apparent, the work really did not appear until late in 1909.[1] This, of course, cannot be laid at the door of Messrs. Beede and Rogers, nor perhaps the fact that the description of the chart begins on p. 359, while the chart is inserted thirty pages earlier, although in the description it is said to follow, thus really confusing

[1] In his review of my report on the Guadalupian fauna (*Jour. Geol.*, XVII [1909], 672), Dr. Beede justly criticizes that book for the same fault. I take this occasion to put the facts on record. The pages were approved with the imprint 1908 on November 14 of that year. Under ordinary conditions this would have given ample time for publication before the end of the year, but owing to occurrences which could not be foreseen publication was delayed. The copies were received on January 29, 1909, and were immediately distributed so that the actual date of publication should probably be regarded as early in February.

the reader. Such errors, however, as ascribing *Seminula argentea* to Morton instead of Shepard, as citing a species of Leda under Nuculana and Leda, two genera which are recognized as being synonymous, and other similar instances, must be credited to the authors alone.

It is doubtless illogical, but it is certainly true, that carelessness in such matters as these, in style and editorship—in brief, carelessness in form in which the work is presented—somehow leads the reader to infer carelessness in the work itself, an imputation which in the present case I do not believe to be deserved but which the authors might do well to guard against in the case of a less friendly critic.

G. H. G.

The Genesis of Loess a Problem in Plant Ecology. By B. SHIMEK. Iowa Academy of Science, pp. 57–64; date not given on separate, probably 1909. Pls. III–VII.

The Loess of the Paha and River-Ridge. By B. SHIMEK. Iowa Academy of Science, pp. 117–24, pls. VIII–XII.

These are critical papers full of important data assembled by a careful observer. They bring strong support to bear in favor of the eolian hypothesis of the loess. The first paper is also notable as an added recognition of the value of uniting the methods of two sciences in the study of composite problems.

T. C. C.

Aftonian Sands and Gravels in Western Iowa. By B. SHIMEK. Bulletin Geological Society of America, Vol. XX, 1909, pp. 399–408, pls. 33–37.

This important paper adds much new data to the distribution and constitution of the Aftonian formation and announces molluscan remains in addition to the mammalian fossils found recently by Calvin and the vegetal remains found earlier. These remains, taken with unconformities also described in this paper, made it clear that the Aftonian is a true interglacial deposit formed under mild climatic conditions and not simply a fluvial phase of the preceding or following ice-deposits.

In a supplementary note Shimek proposes the name Nebraskan for the Sub-Aftonian glacial formation because of what he deems objections to the previous terms Albertan and Jerseyan and an implied objection to the descriptive term Sub-Aftonian. But the facts (1) that the locality at which the formation was first found and its relations first pointed out is in Iowa, (2) that most of the localities now known are in Iowa, (3) that it has

merely been traced into Nebraska recently and incidentally rather than as a part of a critical revisionary study, and (4) that the original locality remains quite as accessible and more typical than the localities in Nebraska, unite to make this proposal of a fourth title a proceeding of doubtful wisdom.

T. C. C.

Die Diamantführenden Gesteine Südafrikas. Ihr Abbau und ihre Aufbereitung. By DR. PERCY A. WAGNER. Pp. 207, 29 text figures, and 2 plates. Berlin: Gebrüder Borntraeger, 1909.

One of the fascinating problems of South African geology is the formation of the peculiar kimberlite pipes and the origin of the diamonds which have made them so famous. This new work will be welcomed as a contribution to that interesting subject. It describes carefully the different phases of the kimberlite which fills the pipes, from the but scarcely altered hardibank through the hard blue ground, soft blue ground, to the completely altered, hydrated, and well-oxidized yellow ground near the surface. The point is made that within the pipes distinct zones can be traced from top to bottom. Because certain individual characteristics, both of the general material and of the diamonds as well, can be traced throughout each zone, several observers have concluded that the pipes were formed and filled by several distinct volcanic eruptions. But the nature of the eruptions which produced these great pipes, and at the same time filled them with breccia, volcanic tuff, and a rather heterogeneous mass of material derived in part from the deep-seated rocks, but containing also fragments of sedimentary formations occurring at higher horizons, has not been brought out very clearly and is perhaps not yet well understood. Contact metamorphic phenomena appear to be of rather limited extent.

An interesting feature described by the author is that, on account of the serpentinization of the olivine in the filling of the pipes, the material has, in some cases, undergone a marked increase in volume. This increase in volume has caused the filling to swell upward and this process has resulted in the striation of the walls of the pipe.

The three principal hypotheses of the origin of the diamonds are discussed. The author argues against the view held by some South African geologists that the diamonds have been derived from disrupted deep-seated eclogites, and favors the theory that the diamonds were developed in the midst of the magma from its own inherent constituents.

Chapters describing in detail the minerals of the pipes and dikes and dealing with the petrography make up about half of the book. The work

ends with chapters on the methods of mining and the statistics of the diamond-mining industry.

R. T. C.

Geographical Essays. By WILLIAM MORRIS DAVIS. Edited by DOUGLAS WILSON JOHNSON. Pp. 777, 130 text figures. Boston: Ginn & Co., 1909.

An endeavor has been made in this volume to meet the growing demand for an edition of Professor Davis' most important geographical essayss Twenty-six of these essays have been reprinted from the pages of the variou. publications in which they originally appeared and grouped under two heads: Part I, embracing twelve educational essays, and Part II, fourteen physiographic essays. The high character of these essays is so familiar to all geologists and geographers that special comment seems superfluous.

R. T. C.

The Cement Resources of Virginia, West of the Blue Ridge. By RAY S. BASSLER, PH.D. Bulletin No. 11 A, Virginia Geological Survey. Pp. 309, 30 plates, and 30 text figures. Charlottesville, 1909.

This report deals essentially with the limestones and shales of Appalachian Virginia—in other words, with the materials there present which may be used in the manufacture of cement. The Cambro-Ordovician limestones have received the greatest attention, though the post-Ordovician cement materials are also discussed toward the close of the book. A large number of chemical analyses of the limestones from the various localities are given. Since practically nothing concerning the Paleozoic fossils of Virginia has appeared in the literature, the author has included plates portraying some of the characteristic species employed in the discrimination of the different formations. The report is well illustrated.

R. T. C.